

# TGD and Nuclear Physics

M. Pitkänen<sup>1</sup>, April 8, 2007

<sup>1</sup> Department of Physical Sciences, High Energy Physics Division,  
PL 64, FIN-00014, University of Helsinki, Finland.  
matpitka@rock.helsinki.fi, <http://www.physics.helsinki.fi/~matpitka/>.  
Recent address: Puutarhurinkatu 10,10960, Hanko, Finland.

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## Abstract

This chapter is devoted to the possible implications of TGD for nuclear physics. In the original version of the chapter the focus was in the attempt to resolve the problems caused by the incorrect interpretation of the predicted long ranged weak gauge fields. What seems to be a breakthrough in this respect came only quite recently (2005), more than a decade after the first version of this chapter, and is based on TGD based view about dark matter inspired by the developments in the mathematical understanding of quantum TGD. In this approach condensed matter nuclei can be either ordinary, that is behave essentially like standard model nuclei, or be in dark matter phase in which case they generate long ranged dark weak gauge fields responsible for the large parity breaking effects in living matter. This approach resolves trivially the objections against long range classical weak fields.

The basic criterion for the transition to dark matter phase having by definition large value of  $\hbar$  is that the condition  $\alpha Q_1 Q_2 \simeq 1$  for appropriate gauge interactions expressing the fact that the perturbation series does not converge. The increase of  $\hbar$  makes perturbation series converging since the value of  $\alpha$  is reduced but leaves lowest order classical predictions invariant.

This criterion can be applied to color force and inspires the hypothesis that valence quarks inside nucleons correspond to large  $\hbar$  phase whereas sea quark space-time sheets correspond to the ordinary value of  $\hbar$ . This hypothesis is combined with the earlier model of strong nuclear force based on the assumption that long color bonds with p-adically scaled down quarks with mass of order MeV at their ends are responsible for the nuclear strong force.

### 1. Is strong force due to color bonds between exotic quark pairs?

The basic assumptions are following.

a) Valence quarks correspond to large  $\hbar$  phase with p-adic length scale  $L(k_{eff} = 129) = L(107)/v_0 \simeq 2^{11}L(107) \simeq 5 \times 10^{-12}$  m whereas sea quarks correspond to ordinary  $\hbar$  and define the standard size of nucleons.

b) Color bonds with length of order  $L(127) \simeq 2.5 \times 10^{-12}$  m and having quarks with ordinary  $\hbar$  and p-adically scaled down masses  $m_q(dark) \simeq v_0 m_q$  at their ends define kind of rubber bands connecting nucleons. The p-adic length scale of exotic quarks differs by a factor 2 from that of dark valence quarks so that the length scales in question can couple naturally. This large length scale as also other p-adic length scales correspond to the size of the topologically quantized field body associated with system, be it quark, nucleon, or nucleus.

Valence quarks and even exotic quarks can be dark with respect to both color and weak interactions but not with respect to electromagnetic interactions. The model for binding energies suggests darkness with respect to weak interactions with weak boson masses scaled down by a factor  $v_0$ . Weak interactions remain still weak. Quarks and nucleons as defined by their  $k = 107$  sea quark portions condense at scaled up weak space-time sheet with  $k_{eff} = 111$  having p-adic size  $10^{-14}$  meters. The estimate for the atomic number of the heaviest possible nucleus comes out correctly.

The wave functions of the nucleons fix the boundary values of the wave functionals of the color magnetic flux tubes idealizable as strings. In the terminology of M-theory nucleons correspond to small branes and color magnetic flux tubes to strings connecting them.

### 2. General features of strong interactions

This picture allows to understand the general features of strong interactions.

a) Quantum classical correspondence and the assumption that the relevant space-time surfaces have 2-dimensional  $CP_2$  projection implies Abelianization. Strong isospin group can be identified as the  $SU(2)$  subgroup of color group acting as isotropies of space-time surfaces. and the  $U(1)$  holonomy of color gauge potential defines a preferred direction of strong isospin. Dark color isospin corresponds to strong isospin. The correlation of dark color with weak isospin of the nucleon is strongly suggested by quantum classical correspondence.

b) Both color singlet spin 0 pion type bonds and colored spin 1 bonds are allowed and the color magnetic spin-spin interaction between the exotic quark and anti-quark is negative in this case. p-p and n-n bonds correspond to oppositely colored spin 1 bonds and p-n bonds to colorless spin 0 bonds for which the binding energy is free times higher. The presence of

colored bonds forces the presence of neutralizing dark gluon condensate favoring states with  $N - P > 0$ .

c) Shell model based on harmonic oscillator potential follows naturally from this picture in which the magnetic flux tubes connecting nucleons take the role of springs. Spin-orbit interaction can be understood in terms of the color force in the same way as it is understood in atomic physics.

### 3. Nuclear binding energies

a) The binding energies per nucleon for  $A \leq 4$  nuclei can be understood if they form closed string like structures, nuclear strings, so that only two color bonds per nucleon are possible. This could be understood if ordinary quarks and exotic quarks possessing much smaller mass behave as if they were identical fermions. p-Adic mass calculations support this assumption. Also the average behavior of binding energy for heavier nuclei is predicted correctly.

b) For nuclei with  $P = N$  all color bonds can be pion type bonds and have thus largest color magnetic spin-spin interaction energy. The increase of color Coulombic binding energy between colored exotic quark pairs and dark gluons however favors  $N > P$  and explains also the formation of neutron halo outside  $k = 111$  space-time sheet.

c) Spin-orbit interaction provides the standard explanation for magic numbers. If the maximum of the binding energy per nucleon is taken as a criterion for magic, also  $Z=N=4,6,12$  are magic. The alternative TGD based explanation for magic numbers  $Z = N = 4, 6, 8, 12, 20$  would be in terms of regular Platonic solids. Experimentally also other magic numbers are known for neutrons. The linking of nuclear strings provides a possible mechanism producing new magic nuclei from lighter magic nuclei.

### 4. Stringy description of nuclear reactions

The view about nucleus as a collection of linked nuclear strings suggests stringy description of nuclear reactions. Microscopically the nuclear reactions would correspond to re-distribution of exotic quarks between the nucleons in reacting nuclei.

### 5. Anomalies and new nuclear physics

The TGD based explanation of neutron halo has been already mentioned. The recently observed tetra-neutron states are difficult to understand in the standard nuclear physics framework since Fermi statistics does not allow this kind of state. The identification of tetra-neutron as an alpha particle containing two negatively charged color bonds allows to circumvent the problem. A large variety of exotic nuclei containing charged color bonds is predicted.

The proposed model explains the anomaly associated with the tritium beta decay. What has been observed [37, 38] is that the spectrum intensity of electrons has a narrow bump near the endpoint energy. Also the maximum energy  $E_0$  of electrons is shifted downwards. I have considered two explanations for the anomaly. The original models are based on TGD variants of original models involving belt of dark neutrinos or antineutrinos along the orbit of Earth. Only recently (towards the end of year 2008) I realized that nuclear string model provides much more elegant explanation of the anomaly and has also the potential to explain much more general anomalies.

Cold fusion has not been taken seriously by the physics community but the situation has begun to change gradually. There is an increasing evidence for the occurrence of nuclear transmutations of heavier elements besides the production of  ${}^4\text{He}$  and  ${}^3\text{H}$  whereas the production rate of  ${}^3\text{He}$  and neutrons is very low. These characteristics are not consistent with the standard nuclear physics predictions. Also Coulomb wall and the absence of gamma rays and the lack of a mechanism transferring nuclear energy to the electrolyte have been used as an argument against cold fusion. TGD based model relying on the notion of charged color bonds explains the anomalous characteristics of cold fusion.

# 1 Introduction

Despite the immense amount of data about nuclear properties, the first principle understanding of the nuclear strong force is still lacking. The conventional meson exchange description works at qualitative level only and does not provide a viable perturbative approach to the description of the strong force. The new concept of atomic nucleus forced by TGD suggests quite different approach to the quantitative description of the strong force in terms of the notion of field body, join along boundaries bond concept, long ranged color gauge fields associated with dark hadronic matter, and p-adic length scale hierarchy.

## 1.1 p-Adic length scale hierarchy

### 1.1.1 p-Adic length scale hypothesis

The concept of the p-adic topological condensate is the corner stone of p-adic TGD. Various levels of the topological condensate obey effective p-adic topology and are assumed to form a p-adic hierarchy ( $p_1 \leq p_2$  can condense on  $p_2$ ). By the length scale hypothesis, the physically interesting length scales should come as square roots of powers of 2:  $L(k) \simeq 2^{\frac{k}{2}} l$ ,  $l \simeq 1.288E + 4\sqrt{G}$  and prime powers of  $k$  are especially interesting.

For nuclear physics applications the most interesting values of  $k$  are:  $k = 107$  (hadronic space-time sheet at which quarks feed their color gauge fluxes),  $k = 109$  (radius of light nucleus such as alpha particle<sup>1</sup>,  $k = 113$  (the space-time at which quarks feed their electromagnetic gauge fluxes),  $k = k_{em} = 127$  or  $131$  (electronic or atomic space-time sheet receiving electromagnetic gauge fluxes of nuclei).

The so called Gaussian primes are to complex integers what primes are for the ordinary integers and the Gaussian counterparts of the Mersenne primes are Gaussian primes of form  $(1 \pm i)^k - 1$ . Rather interestingly,  $k = 113$  corresponds to a Gaussian Mersenne. Also the primes  $k = 151, 157, 163, 167$  defining biologically important length scales correspond to Gaussian Mersennes. Thus the electromagnetic p-adic length scales associated with quarks, hadrons, and nuclear physics as well as with muon are in well defined sense also Mersenne length scales. A possible interpretation for complex primes is in terms of complex conformal weights for elementary particles. If the net conformal weights of physical states are required to be real this gives rise to conformal confinement.

There are however arguments [C5] suggesting the conformal weights can be complex for particles and that the imaginary part of the conformal weight defines a new kind of conserved quantum number, "scaling momentum", whose sign distinguishes between particles and their phase conjugates which can be regarded as particles of negative energy travelling to the direction of geometric past. There would be inherent arrow of geometric time associated with particles with complex conformal weight. For instance, the strange properties of phase conjugate photons could be understood since second law of thermodynamics would hold true in a reversed direction of geometric time for them.

### 1.1.2 Particles are characterized by a collection of p-adic primes

It seems that is not correct to speak about particle as a space-time sheet characterized by single p-adic prime. Already p-adic mass calculations suggest that there are several sizes corresponding to space-time sheets at which particle feeds its gauge charges. p-Adic length scale hypothesis provides further insight: the length scale is more like the size of field body and possibly also delocalization volume of particle determining the p-adic mass scale in p-adic thermodynamics rather than the geometric size for the elementary particle.

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<sup>1</sup>For some mysterious reason I realized that  $k = 109$  is also prime only at the third millenium: for more than half decade after writing the first version of this chapter!

What one can definitely say that each particle is characterized by a collection of p-adic primes and one of them characterizes the mass scale of the particle whereas other characterize its interactions. There are two possible interpretations and both of them allow to resolve objections against p-adic hierarchies of color and electro-weak physics.

1. These primes characterize the space-time sheets at which it feeds its gauge fluxes and particles can interact only via their common space-time sheets and are otherwise dark with respect to each other.
2. Number theoretical vision supports the notion of multi-p p-adicity and the idea that elementary particles correspond to infinite primes, integers, or perhaps even rationals [E3, F6]. To infinite primes, integers, and rationals it is possible to associate a finite rational  $q = m/n$  by a homomorphism.  $q$  defines an effective q-adic topology of space-time sheet consistent with p-adic topologies defined by the primes dividing  $m$  and  $n$  ( $1/p$ -adic topology is homeomorphic to p-adic topology). The largest prime dividing  $m$  determines the mass scale of the space-time sheet in p-adic thermodynamics.  $m$  and  $n$  are exchanged by super-symmetry and the primes dividing  $m$  ( $n$ ) correspond to space-time sheets with positive (negative) time orientation. Two space-time sheets characterized by rationals having common prime factors can be connected by a  $\#_B$  contact and can interact by the exchange of particles characterized by divisors of  $m$  or  $n$ .

The nice feature of this option is that single multi-p p-adic space-time sheet rather than a collection of them characterizes elementary particle. Concerning the description of interaction vertices as generalization of vertices of Feynman graphs (vertices as branchings of 3-surfaces) this option is decisively simpler than option 1) and is consistent with earlier number theoretic argument allowing to evaluate gravitational coupling strength [E3, F6]. It is also easier to understand why the largest prime in the collection determines the mass scale of elementary particle.

Interestingly, these two options are not necessarily mutually exclusive: single multi-p p-adic space-time sheet could correspond to many-sheeted structure with respect to real topology.

### 1.1.3 What is the proper interpretation of p-adic length scales

One of the surprises of p-adic mass calculations was that for  $u$  and  $d$  quarks electromagnetic size corresponds to  $k = 113$  which corresponds to the length scale of  $2 \times 10^{-14}$  m. This leads to the view that also hadrons and nuclei have this size in some sense. The charge radii of even largest nuclei without neutron halo are smaller than this.

1. If electromagnetic charges of quarks inside nucleons were separately delocalized in the scale  $L(113)$ , also the distributions of electromagnetic charges of nuclei would be non-trivial in surprisingly long length scale. Em charges would exhibit fractionality in this length scale and Rutherford scattering cross sections would be modified. The fact that the height of the Coulomb wall at  $L(113)$  is lower than the observed heights of the Coulomb wall would lead to a paradox.

This suggests that the p-adic length scale  $L(113)$  does not characterize the geometric size of neither nucleons nor nuclei but to the size, perhaps height, of the electromagnetic field body associated with quark/hadron/nucleus.

2. If protons feed their electric em gauge fluxes to the same space-time sheet, there is an electromagnetic harmonic oscillator potential contributing to the nuclear energies. The Mersenne prime  $M_{127}$  as a characterizer of the field body of nucleus is natural and it also corresponds to the space-time sheet of electron.

3. For weak forces the size of the field body would be given by electro-weak length scale  $L(89)$ . The size scale would also correspond to the p-adic delocalization length scale of ordinary sized nucleons and nuclei.
4. It turns out that the identification of nuclear strong interactions in terms of dark QCD with large value of  $\hbar$  and color length scale scaled up to  $L_c \simeq 2^{11}L(107) \simeq .5 \times 10^{-11}$  m (!) predicts for the nuclei same electromagnetic sizes as in the conventional theory: scaled up sizes appear only in the dark sector and characterize the size of color field body so that paradoxes are avoided. There are also reasons to believe that dark quarks are dark also with respect to electromagnetic and weak interactions so that the sizes of corresponding field bodies are scaled up by a factor  $1/v_0$ .

The hypothesis that the collection of primes corresponds to multi-p p-adicity rather than collection of space-time sheets implies this. For this option various field bodies could form single field body in q-adic sense with superposed p-adic fractalities much like waves of shorter wavelength scale superposed on waves of longer wavelength scale. As noticed, this might be consistent with the existence of several p-adic field bodies with respect to real topology.

Field/magnetic bodies would represent the space-time correlate for the formation of bound states. It is even possible to think that bound state entanglement corresponds to the linking of magnetic flux tubes. The contributions of say color interactions between nucleons to the binding energy would be estimated using the field magnitudes at position of exotic quarks and the hypothesis is made that these intensities correlate with the shortest distance between dark quarks although the distance along the field body is of order  $L_c$ .

This picture finds experimental support.

1. Neutron proton scattering at low energies gives however surprisingly clear evidence for the presence of the p-adic length scales  $L(109)$  ( $k = 109$  is prime) and  $L(113)$  in nuclear physics. The scattering lengths for s and p waves are  $a_s = -2.37 \times 10^{-14}$  m and  $a_t = 5.4 \times 10^{-15}$  m [19].  $a_s$  is anomalously large and the standard explanation is that deuteron almost allows singlet wave bound state.  $a_t$  is near to  $L(109) = 2L(107) \simeq 5.0 \times 10^{-15}$  m, which is in accordance with the assumption that in triplet state neutron and proton are glued by color bond together to form structure with size or order  $L(109) = 2L(107)$ .  $a_s$  is of same order of magnitude as  $L(113) = 2 \times 10^{-14}$  m so that the interpretation in terms of the  $k = 113$  space-time sheet is suggestive.
2. Neutron halos at distance of about  $2.5 \times 10^{-14}$  m longer than even  $L(113) = 2 \times 10^{-14}$  m are difficult to understand in the standard nuclear physics framework and provide support for the large value of  $L_c$ . They could be understood in terms of delocalization of quarks in the length scale  $L(113)$  and color charges in the length scale of  $L_c$ . For instance, the nucleus in the center could be color charged and neutron halo would be analogous to a colored matter around the central halo.

## 1.2 TGD based view about dark matter

TGD suggests an explanation of dark matter as a macroscopically quantum coherent phase residing at larger space-time sheets [J6].

1. TGD suggests that  $\hbar$  is dynamical and possesses a spectrum expressible in terms of generalized Beraha numbers  $B_r = 4\cos^2(\pi/r)$ , where  $r > 3$  is a rational number [C6, J6]. Just above  $r = 3$  arbitrarily large values of  $\hbar$  and thus also macroscopic quantum phases are possible. The criterion for transition to large  $\hbar$  phase is the failure of perturbative expansion so that Mother Nature takes care of the problems of theoretician. A good guess is that the



criticality condition reads as  $Q_1 Q_2 \alpha \simeq 1$  where  $Q_i$  are gauge charges and  $\alpha$  gauge coupling strength. This leads to universal properties of the large  $\hbar$  phase. For instance,  $\hbar$  is scaled in the transition to dark phase by a harmonic or subharmonic of parameter  $1/v_0 \simeq 2^{11}$  which is essentially the ratio of  $CP_2$  length scale and Planck length [D6, J6]. The criticality condition can be applied also to dark matter itself and entire hierarchy of dark matters is predicted corresponding to the spectrum of values of  $\hbar$ .

2. The particles of dark matter can also carry phase carry complex conformal weights but the net conformal weights for blocks of this kind of dark matter would be real. This implies macroscopic quantum coherence. It is not absolutely necessary that  $\hbar$  is large for this phase.
3. From the point of view of nuclear physics application of this hypothesis is to QCD. The prediction is that the electromagnetic Compton sizes of dark quarks are scaled from  $L(107)$  to about  $2^{11}L(107) = L(129) = 2L(127)$ , which is larger than the p-adic electromagnetic size of electron! The classical scattering cross sections are not changed but changes the geometric sizes of dark quarks, hadrons, and nuclei. The original hypothesis that ordinary valence quarks are dark whereas sea quarks correspond to ordinary value of  $\hbar$  is taken as a starting point. In accordance with the earlier model, nucleons in atomic nuclei are assumed to be accompanied by color bonds connecting exotic quark and anti-quark characterized p-adic length scale  $L(127)$  with ordinary value of  $\hbar$  and having thus scaled down mass of order MeV. The strong binding would be due the color bonds having exotic quark and anti-quark at their ends.
4. Quantum classical correspondence suggests that classical long ranged electro-weak gauge fields serve as classical space-time correlates for dark electro-weak gauge bosons, which are massless. This hypothesis could explain the special properties of bio-matter, in particular the chiral selection as resulting from the coupling to dark  $Z^0$  quanta. Long range weak forces present in TGD counterpart of Higgs=0 phase should allow to understand the differences between biochemistry and the chemistry of dead matter.

The basic implication of the new view is that the earlier view about nuclear physics applies now to dark nuclear physics and large parity breaking effects and contribution of  $Z^0$  force to scattering and interaction energy are not anymore a nuisance.

5. For ordinary condensed matter quarks and leptons  $Z^0$  charge are screened in electro-weak length scale whereas in dark matter  $k = 89$  electro-weak space-time sheet have suffered a phase transition to a p-adic topology with a larger value of  $k$ . Gaussian Mersennes, in particular those associated with  $k = 113, 151, 157, 163, 167$  are excellent candidates in this respect. The particles of this exotic phase of matter would have complex conformal weights closely related to the zeros of Riemann Zeta. The simplest possibility is that they correspond to a single non-trivial zero of Zeta and there is infinite hierarchy of particles of this kind.

In dark matter phase weak gauge fluxes could be feeded to say  $k = k_Z = 169$  space-time sheet corresponding to neutrino Compton length and having size of cell. For this scenario to make sense it is essential that p-adic thermodynamics predicts for dark quarks and leptons essentially the same masses as for their ordinary counterparts [F3].

### 1.3 The identification of long range classical weak gauge fields as correlates for dark massless weak bosons

Long ranged electro-weak gauge fields are unavoidably present when the dimension  $D$  of the  $CP_2$  projection of the space-time sheet is larger than 2. Classical color gauge fields are non-vanishing for all non-vacuum extremals. This poses deep interpretational problems. If ordinary quarks and

leptons are assumed to carry weak charges feeded to larger space-time sheets within electro-weak length scale, large hadronic, nuclear, and atomic parity breaking effects, large contributions of the classical  $Z^0$  force to Rutherford scattering, and strong isotopic effects, are expected. If weak charges are screened within electro-weak length scale, the question about the interpretation of long ranged classical weak fields remains.

During years I have discussed several solutions to these problems.

*Option I:* The trivial solution of the constraints is that  $Z^0$  charges are neutralized at electro-weak length scale. The problem is that this option leaves open the interpretation of classical long ranged electro-weak gauge fields unavoidably present in all length scales when the dimension for the  $CP_2$  projection of the space-time surface satisfies  $D > 2$ .

*Option II:* Second option involves several variants but the basic assumption is that nuclei or even quarks feed their  $Z^0$  charges to a space-time sheet with size of order neutrino Compton length. The large parity breaking effects in hadronic, atomic, and nuclear length scales is not the only difficulty. The scattering of electrons, neutrons and protons in the classical long range  $Z^0$  force contributes to the Rutherford cross section and it is very difficult to see how neutrino screening could make these effects small enough. Strong isotopic effects in condensed matter due to the classical  $Z^0$  interaction energy are expected. It is far from clear whether all these constraints can be satisfied by any assumptions about the structure of topological condensate.

*Option III:* During 2005 (27 years after the birth of TGD!) third option solving the problems emerged based on the progress in the understanding of the basic mathematics behind TGD.

In ordinary phase the  $Z^0$  charges of elementary particles are indeed neutralized in intermediate boson length scale so that the problems related to the parity breaking, the large contributions of classical  $Z^0$  force to Rutherford scattering, and large isotopic effects in condensed matter, trivialize.

Classical electro-weak gauge fields in macroscopic length scales are identified as space-time correlates for the gauge fields created by dark matter, which corresponds to a macroscopically quantum coherent phase for which elementary particles possess complex conformal weights such that the net conformal weight of the system is real.

In this phase  $U(2)_{ew}$  symmetry is not broken below the scaled up weak scale except for fermions so that gauge bosons are massless below this length scale whereas fermion masses are essentially the same as for ordinary matter. By charge screening gauge bosons look massive in length scales much longer than the relevant p-adic length scale. The large parity breaking effects in living matter (chiral selection for bio-molecules) support the view that dark matter is what makes living matter living.

Classical long ranged color gauge fields always present for non-vacuum extremals are interpreted as space-time correlates of gluon fields associated with dark copies of hadron physics. It seems that this picture is indeed what TGD predicts.

#### 1.4 Dark color force as a space-time correlate for the strong nuclear force?

Color confinement suggests a basic application of the basic criteria for the transition to large  $\hbar$  phase. The obvious guess is that valence quarks are dark [J6, F10]. Dark matter phase for quarks does not change the lowest order classical strong interaction cross sections but reduces dramatically higher order perturbative corrections and resolves the problems created by the large value of QCD coupling strength in the hadronic phase.

The challenge is to understand the strong binding solely in terms of dark QCD with large value of  $\hbar$  reducing color coupling strength of valence quarks to  $v_0 \simeq 2^{-11}$ . The best manner to introduce the basic ideas is as a series of not so frequently asked questions and answers.

#### 1.4.1 Rubber band model of strong nuclear force as starting point

The first question is what is the vision for nuclear strong interaction that one can start from. The sticky toffee model of Chris Illert [36] is based on the paradox created by the fact alpha particles can tunnel from the nucleus but that the reversal of this process in nuclear collisions does not occur. Illert proposes a classical model for the tunnelling of alpha particles from nucleus based on dynamical electromagnetic charge. Illert is forced to assume that virtual pions inside nuclei have considerably larger size than predicted by QCD and the model. Strikingly, the model favors fractional alpha particle charges at the nuclear surface. The TGD based interpretation would be based on the identification of the rubber bands of Illert as long color bonds having exotic light quark and anti-quark at their ends and connecting escaping alpha particle to the mother nucleus. The challenge is to give meaning to the attribute "exotic".

#### 1.4.2 How the darkness of valence quarks can be consistent with the known sizes of nuclei?

The assumption about darkness of valence quarks in the sense of large  $\hbar$  ( $\hbar_s = \hbar/v_0$ ) is very natural if one takes the basic criterion for darkness seriously. The obvious question is how the dark color force can bind the nucleons to nuclei of ordinary size if the strength of color force is  $v_0$  and color sizes of valence quarks are about  $L(129)$ ?

It seems also obvious that  $L(107)$  in some sense defines the size for nucleons, and somehow this should be consistent with scaled up size  $L(k_{eff} = 129)$  implied by the valence quarks with large  $\hbar$ . The proposal of [J6, F10] inspired by RHIC findings [33] is that valence quarks are dark in the sense of having large value of  $\hbar$  and thus correspond to  $k_{eff} = 129$  whereas sea quarks correspond to ordinary value for  $\hbar$  and give rise to the QCD size  $\sim L(107)$  of nucleon.

If one assumes that the typical distances between sea quark space-time sheets of nucleons is obtained by scaling down the size scale of valence quarks, the size scale of nuclei comes out correctly.

#### 1.4.3 Valence quarks and exotic quarks cannot be identical

The hypothesis is that nucleons contain or there are associated with them pairs of exotic quarks and flux tubes of color field bodies of size  $\sim L(129)$  connecting the exotic quark and anti-quark in separate nuclei. Nucleons would be structures with the size of ordinary nucleus formed as densely packed structures of size  $L(129)$  identifiable as the size of color magnetic body.

The masses of exotic quarks must be however small so that they must differ from valence quarks. The simplest possibility is that exotic quarks are not dark but p-adically scaled down versions of sea quarks with ordinary value of  $\hbar$  having  $k = 127$  so that masses are scaled down by a factor  $2^{-10}$ .

Energetic considerations favor the option that exotic quarks associate with nucleons via the  $k_{eff} = 111$  space-time sheets containing nucleons and dark quarks. Encouragingly, the assumption that nucleons topologically condense at the weak  $k_{eff} = 111$  space-time sheet of size  $L(111) \approx 10^{-14}$  m of exotic quarks predicts essentially correctly the mass number of the highest known super-massive nucleus. Neutron halos are outside this radius and can be understood in terms color Coulombic binding by dark gluons. Tetra-neutron can be identified as alpha particle containing two negatively charged color bonds.

#### 1.4.4 What determines the binding energy per nucleon?

The binding energies per nucleon for  $A \geq 4$  do not vary too much from 7 MeV but the lighter nuclei have anomalously small binding energies. The color bond defined by a color magnetic flux tube of length  $\sim L(k = 127)$  or  $\sim L(k_{eff} = 129)$  connecting exotic quark and anti-quark in separate nucleons with scaled down masses  $m_q(dark) \sim xm_q$ , with  $x = 2^{-10}$  for option for

$k = 127$ , is a good candidate in this respect. Color magnetic spin-spin interaction would give the dominant contribution to the interaction energy as in the case of hadrons. This interaction energy is expected to depend on exotic quark pair only. The large zero point kinetic energy of light nuclei topologically condensed at  $k_{eff} = 111$  space-time sheet having possible identification as the dark variant of  $k = 89$  weak space-time sheet explains why the binding energies of D and  ${}^3\text{He}$  are anomalously small.

#### 1.4.5 What can one assume about the color bonds?

Can one allow only quark anti-quark type color bonds? Can one allow the bonds to be also electromagnetically charged as the earlier model for tetra-neutron suggests (tetra-neutron would be alpha particle containing two negatively charged color bonds so that the problems with the Fermi statistics are circumvented). Can one apply Fermi statistics simultaneously to exotic quarks and anti-quarks and dark valence quarks?

Option I: Assume that exotic and dark valence quarks are identical in the sense of Fermi statistics. This assumption sounds somewhat non-convincing but is favored by p-adic mass calculations supporting the view that the p-adic mass scale of hadronic quarks can vary. If this hypothesis holds true at least effectively, very few color bonds from a given nucleon are allowed by statistics and there are good reasons to argue that nucleons are arranged to highly tangled string like structures filling nuclear volume with two nucleons being connected by color bonds having of length of order  $L(129)$ . The organization into closed strings is also favored by the conservation of magnetic flux.

The notion of nuclear string is strongly supported by the resulting model explaining the nuclear binding energies per nucleon. It is essential that nucleons form what might be called nuclear strings rather than more general tangles. Attractive p-p and n-n bonds must correspond to colored  $\rho_0$  type bonds with spin one and attractive p-n type bonds to color singlet pion type bonds. The quantitative estimates for the spin-spin interaction energy of the lightest nuclei lead to more precise estimates for the lengths of color bonds. The resulting net color quantum numbers must be compensated by dark gluon condensate, the existence of which is suggested by RHIC experiments [33]. This option is strongly favored by the estimate of nuclear binding energies.

Option II: If Fermi statistics is not assumed to apply in the proposed manner, then color magnetic flux tubes bonds between any pair of nucleons are possible. The identification of color isospin as strong isospin still effective removes color degree of freedom. As many as 8 color tubes can leave the nucleus if exotic quarks and anti-quarks are in the same orbital state and a cubic lattice like structure would become possible. This picture would be consistent with the idea that in ordinary field theory all particle pairs contribute to the interaction energy. The large scale of the magnetic flux tubes would suggest that the contributions cannot depend much on particle pair. The behavior of the binding energies favors strongly the idea of nuclear string and reduces this option to the first one.

#### 1.4.6 What is the origin of strong force and strong isospin?

Here the answer is motivated by the geometry of  $CP_2$  allowing to identify the holonomy group of electro-weak spinor connection as  $U(2)$  subgroup of color group. Strong isospin group  $SU(2)$  is identified as subgroup of isotropy group  $U(2)$  for space-time surfaces in a sub-theory defined by  $M^4 \times S^2$ ,  $S^2$  a homologically non-trivial geodesic sphere of  $CP_2$  and second factor of  $U(1) \times U(1)$  subgroup of the holonomies for the induced Abelian gauge fields corresponds to strong isospin component  $I_3$ . The extremely tight correlations between various classical fields lead to the hypothesis that the strong isospin identifiable as color isospin  $I_3$  of exotic quarks at the ends of color bonds attached to a given nucleon is identical with the weak isospin of the nucleon. Note that this does not require that exotic and valence quarks are identical particles in the sense of Fermi statistics.

Does the model explain the strong spin orbit coupling ( $L \cdot S$  force)? This force can be identified as an effect due to the motion of fermion string containing the effectively color charged nucleons in the color magnetic field  $v \times E$  induced by the motion of string in the color electric field at the dark  $k = 107$  space-time sheet.

#### 1.4.7 How the phenomenological shell model with harmonic oscillator potential emerges?

Nucleus can be seen as a collection of long color magnetic flux tubes glued to nucleons with the mediation of exotic quarks and anti-quarks. If nuclei form closed string, as one expects in the case of Fermi statistics constraint, also this string defines a closed string or possibly a collection of linked and knotted closed strings. If Fermi statistics constraint is not applied, the nuclear strings form a more complex knotted and linked tangle. The stringy space-time sheets would be the color magnetic flux tubes connecting exotic quarks belonging to different nucleons.

The color bonds between the nucleons are indeed strings connecting them and the averaged interaction between neighboring nucleons in the nuclear string gives in the lowest order approximation 3-D harmonic oscillator potential although strings have  $D = 2$  transversal degrees of freedom. Even in the case that nucleons for nuclear strings and thus have only two bonds to neighbors the average force around equilibrium position is expected to be a harmonic force in a good approximation. The nuclear wave functions fix the restrictions of stringy wave functionals to the positions of nucleons at the nuclear strings. Using M-theory language, nucleons would represent branes connected by color magnetic flux tubes representing strings whose ends co-move with branes.

#### 1.4.8 Which nuclei are the most stable ones and what is the origin of magic numbers?

$P = N$  closed strings correspond to energy minima and their deformations obtained by adding or subtracting nucleons in general correspond to smaller binding energy per nucleon. Thus the observed strong correlation between P and N finds a natural explanation unlike in the harmonic oscillator model. For large values of  $A$  the generation of dark gluon condensate and corresponding color Coulombic binding energy favors the surplus of neutrons and the generation of neutron halos. The model explains also the spectrum of light nuclei, in particular the absence of pp, nn, ppp, and nnn nuclei.

In the standard framework spin-orbit coupling explains the magic nuclei and color Coulombic force gives rise to this kind of force in the same manner as in atomic physics context. Besides the standard magic numbers there are also non-standard ones (such as  $Z, N = 6, 12$ ) if the maximum of binding energy is taken as a definition of magic, there are also other magic numbers than the standard ones. Hence can consider also alternative explanations for magic numbers. The geometric view about nucleus suggests that the five Platonic regular solids might defined favor nuclear configurations and it indeed turns that they explain non-standard magic numbers for light nuclei.

New magic nuclei might be obtained by linking strings representing doubly magic nuclei. An entire hierarchy of linkings becomes possible and could explain the new magic numbers 14, 16, 30, 32 discovered for neutrons [29]. Linking of the nuclear strings could be rather stable by Pauli Exclusion Principle. For instance,  $^{16}\text{O}$  would corresponds to linked  $^4\text{He}$  and  $^{12}\text{C}$  nuclei. Higher magic numbers 28, 50, ... allow partitions to sums of lower magic numbers which encourages to consider the geometric interpretation as linked nuclei. p-Adic length scale hypothesis in turn suggest the existence of magic numbers coming as powers of  $2^3$ .

#### 1.4.9 What about the description of nuclear reactions?

The identification of nuclei as linked and knotted strings filling the nuclear volume for constant nuclear density leads to a topological description for the nuclear reactions with simplest reactions

corresponding to fusion and fission of closed nuclear strings. The microscopic description is in terms of nucleon collisions in which exotic quarks and anti-quarks are re-shared between nucleons and also new pairs are created. The distinction to ordinary string model is that the topological reactions for strings can occur only when the points at which where they are attached to nucleons collide.

The old fashioned description of the nuclear strong force is based on the meson exchange picture. The perturbation theory based on the exchange of pions doesn't however make sense in practice. In the hadronic string model this description would be replaced by hadronic string diagrams. The description of nuclear scattering in terms of nuclear strings allows phenomenological interpretation in terms of stringy diagrams but color bonds between nucleons do not correspond to meson exchanges but are something genuinely new.

## 1.5 Tritium beta decay anomaly

The proposed model explains the anomaly associated with the tritium beta decay. What has been observed [37, 38] is that the spectrum intensity of electrons has a narrow bump near the endpoint energy. Also the maximum energy  $E_0$  of electrons is shifted downwards.

I have considered two explanations for the anomaly. The original models are based on TGD variants of original models [39, 40] involving belt of dark neutrinos or antineutrinos along the orbit of Earth. Only recently (towards the end of year 2008) I realized that nuclear string model provides much more elegant explanation of the anomaly and has also the potential to explain much more general anomalies [41, 42, 43].

## 1.6 Cold fusion and Trojan horse mechanism

Cold fusion [56] has not been taken seriously by the physics community but the situation has begun to change gradually. There is an increasing evidence for the occurrence of nuclear transmutations of heavier elements besides the production of  ${}^4\text{He}$  and  ${}^3\text{H}$  whereas the production rate of  ${}^3\text{He}$  and neutrons is very low. These characteristics are not consistent with the standard nuclear physics predictions. Also Coulomb wall and the absence of gamma rays and the lack of a mechanism transferring nuclear energy to the electrolyte have been used as an argument against cold fusion.

An additional piece to the puzzle came when Ditmire *et al* [48] observed that the spectrum of electron energies in laser induced explosions of ion clusters extends up to energies of order MeV (rather than  $10^2$  eV!): this suggests that strong interactions are involved.

The possibility of charged color bonds explaining tetra-neutron allows to construct a model explaining both the observations of Ditmire *et al* and cold fusion and nuclear transmutations. 'Trojan horse mechanism' allows to circumvent the Coulomb wall, and explains various selection rules and the absence of gamma rays, and also provides a mechanism for the heating of electrolyte.

## 2 Model for the nucleus based on exotic quarks

The challenge is to understand the strong binding solely in terms of the color bonds and large value of  $\hbar$  for valence quarks reducing color coupling strength to  $v_0$  and scaling there sizes to  $L(107)/v_0 = L(129)$ . There are many questions to be answered. How exotic quarks with scaled down masses differ from dark valence quarks? How the model can be consistent with the known nuclear radii of nuclei if valence quarks have Compton length of order  $L(129)$ ?

## 2.1 The notion of color bond

The basic notion is that of color bond having exotic quark and anti-quark at its ends. Color bonds connecting nucleons make them effectively color charged so that nuclei can be regarded as color bound states of nucleons glued together using color bonds.

The motivation for the notion of color bond comes from the hypothesis that valence quarks are in large  $\hbar$  phase, and also from the ideas inspired by the work of Chris Illert [36] suggesting that long virtual pions act as "rubber bands" connecting nucleons to each other. There are indications that the quark distribution functions for the nucleons inside nuclei differ from those for free nucleons [18, 17]. QCD based estimates show that color van der Waals force is not involved [17]. The contribution of the quark pairs associated with color bonds is a possible explanation for this phenomenon.

## 2.2 Are the quarks associated with color bonds dark or p-adically scaled down quarks?

What seems clear is that color bonds with light quark and antiquark, to be referred as exotic quarks in the sequel, at their ends could explain strong nuclear force. Concerning the identification of the exotic quarks there are frustratingly many options. In lack of deeper understanding, the only manner to proceed is to try to make a detailed comparison of various alternatives in hope of identifying a unique internally consistent option.

The basic observation is that if four-momentum is conserved in the phase transition to the dark phase, the masses of quarks in large  $\hbar$  phase should not differ from those in ordinary phase, which means that Compton lengths and p-adic length scale are scaled up by a factor  $1/v_0$ . This assumption explains elegantly cold fusion and many other anomalies [F10, J6]. The quarks at the ends of color bonds must however have scaled down masses to not affect too much the masses of nuclei. This option would also allow to identify valence and possibly also sea quarks as dark quarks in accordance with the general criterion for the transition to dark phase as proposed in the model for RHIC events [33, J6].

Exotic quarks must be light. Hence there should be some difference between exotic and valence quarks. This leaves two options to consider.

### 2.2.1 Are the exotic quarks p-adically scaled down versions of ordinary quarks with ordinary value of $\hbar$ ?

Exotic quarks could simply correspond to longer p-adic length scale, say  $M_{127}$  and thus having masses scaled down by a factor  $2^{-10}$  but ordinary value of  $\hbar$ . One can also consider the possibility that they correspond to a QCD associated with  $M_{127}$  as proposed earlier. They could also correspond to their own weak length scale and weak bosons. This would resolve the objections against new elementary particles coming from the decay widths of intermediate gauge bosons even without assumption about the loss of asymptotic freedom implying that the QCD in question effectively exists only in finite length scale range.

p-Adic mass calculations indeed support the view to that hadronic quarks appear as several scaled up variants and there is no reason to assume that also scaled down variants could not appear. This hypothesis leads to correct order of magnitude estimates for the color magnetic spin-spin interaction energy.

For this option valence (and possibly also sea) quarks could be dark and have color sizes of order  $L(k_{eff} = 129)$  as suggested by the criterion  $\alpha_s Q_c^2 \simeq 1$  for color confinement as a transition to a dark phase.

## 2.2.2 Do exotic quarks correspond to large $\hbar$ and reduced $c$ ?

If valence quarks are dark one can wonder why not also exotic quarks are dark and whether there exists a mechanism reducing their masses by a factor  $v_0$ .

If one questions the assumption that  $\hbar$  is a fundamental constant, sooner or later also the question "What about  $c$ ?" pops up. There are indeed motivations for expecting that  $c$  has a discrete spectrum in a well-defined sense. TGD predicts an infinite variety of warped vacuum extremals defining imbeddings of  $M^4$  to  $M^4 \times CP_2$  with  $g_{tt} = \sqrt{1 - R^2\omega^2}$ ,  $g_{ij} = -\delta_{ij}$ , and if common  $M^4$  time coordinate is used for them the maximal signal velocity is for them given by  $c_{\#}/c = \sqrt{1 - R^2\omega^2}$ .

Physically this means that the time taken for light to travel between point A and B depends on what space-time sheet the light travels even in the case that gravitational and gauge fields are absent. The fact that the analog of Bohr quantization occurs for the deformed vacuum extremals of Kähler action suggests that  $c_{\#}$  has a discrete spectrum.

This inspires the question whether also light velocity  $c$  besides  $\hbar$  is quantized in powers of  $v_0$  so that the rest energies of dark quarks would be given by  $E_0 = \hbar_s c_{\#}/L(k_{eff} = k + 22) = \hbar c_{\#}/L(k)$  and scale down because of the scaling  $c \rightarrow v_0 \times c$ . A distinction between rest mass and rest energy should be made since rest mass is scaled up as  $M \rightarrow M/v_0$ . Compton time would be by a factor  $1/v_0^2$  longer than the ordinary Compton time.

If  $c$  and  $\hbar$  can scale up separately but in powers of  $v_0$  (or its harmonics and sub-harmonics) it is possible to have a situation in which  $\hbar c$  remains invariant because mass scale is reduced  $v_0$  and  $\hbar$  is increased by  $1/v_0$ . In the case of dark quarks this would mean that light would propagate with velocity  $2^{-11}c$  along various space-time sheets associated with dark quarks.

This admittedly complex looking option would mean that valence quarks have large  $\hbar$  but ordinary  $c$  and exotic quarks have large  $\hbar$  but small  $c$  due to the warping of their space-time sheet in time direction.

## 2.3 Electro-weak properties of exotic and dark quarks

### 2.3.1 Are exotic quarks scaled down with respect to electromagnetic interactions?

The earlier models involving large  $\hbar$  rely on the assumption that the transition to large  $\hbar$  phase with respect to electromagnetic interactions occurs only under special conditions (models for cold fusion and structure of water represent basic examples). Hence valence quarks can be in large  $\hbar$  phase only with respect to strong and possibly weak interactions.

1. For p-adically scaled down exotic quarks also the electromagnetic space-time sheet should correspond to scaled up value of  $k$  since  $k = 113$  would give too large contribution to the quark mass. It is not clear whether both em and color space-time sheets can correspond to  $k = 127$  or whether one must have  $k_{em} = 131$ .
2. For exotic quarks with large  $\hbar$  and small  $c$  the situation can be different  $k = 107$  contribution to quark mass is scaled down by  $v_0$  factor:  $m_q(dark) = v_0 m_q \sim .05$  MeV. Since  $k = 113$  contributes a considerable fraction to hadron mass, one can argue that also the  $k = 113$  contribution to the mass must be scaled down so that dark quarks would be also electromagnetically dark. If so, the size of  $k = 113$  dark electromagnetic field body would be of order atomic size and nuclei would represent in their structure also atomic length scale.

### 2.3.2 Are exotic and dark quarks scaled down with respect to weak interactions?

What about darkness of exotic and dark quarks with respect to weak interactions? The qualitative behavior of the binding energies of  $A \leq 4$  nuclei can be understood if they possess zero point kinetic



energy associated with space-time sheet with size characterized by  $L(k = 111 = 3 \times 37) \simeq 10^{-14}$  m. Also the maximal mass number of super-heavy nuclei without neutron halo is predicted correctly.  $k_{eff} = 111$  happens to correspond to the scaled weak length scale  $M_{89}$  which raises the possibility that dark quarks correspond to large value of  $\hbar$  with respect to weak interactions. This could be the case for dark valence quarks and both identifications of exotic quarks.

1. For  $k = 127$  quarks with dark weak interactions no large parity breaking effects are induced neither below mass scale  $m_W$ .
2. For large  $\hbar$ -small  $c$  option the scale invariance of gauge interactions would mean that the masses of the corresponding weak bosons are of order 50 MeV but the weak interaction rates of are scaled down by a factor  $v_0^2$  since the ratios  $m_q/m_W$  invariant under the transition to dark phase appear in the rates: this at energy scale smaller than  $v_0 m_w$ . This disfavors this option.

## 2.4 How the statistics of exotic and ordinary quarks relate to each other?

Exotic and ordinary quarks should be identical or in some sense effectively identical in order that nuclear string picture would result.

### 2.4.1 Can one regard exotic quarks and ordinary quarks as identical fermions?

The first guess would be that this is not the case. One must be however cautious. The fact that p-adically scaled up variants of quarks appear in the model of hadrons suggested by p-adic mass calculations, suggests that the scaled up versions must be regarded as identical fermions. Since also the scaling of  $\hbar$  induces only a scaling up of length scale, one might argue that this conclusion holds true quite generally.

Identity is also favored by a physical argument. If identity holds true, Fermi statistics forces the nucleons to form closed nuclear strings to maximize their binding energies. The notion nuclear string explains nicely the behavior nuclear binding energies per nucleon and also suggests that linking and knotting could define mechanisms for nuclear binding.

### 2.4.2 Could dark quarks and ordinary quarks be only effectively identical?

The idea of regarding quarks and dark quarks as identical fermions does not sound convincing, and one can ask the idea could make sense in some effective sense only.

1. The effective identity follows from a model for matter antimatter symmetry assuming that ordinary quarks form strongly correlated pairs with dark anti-quarks so that nucleons would be accompanied by dark antinucleons and quarks and dark quarks would be effectively identical. This option looks however rather science fictive and involves un-necessarily strong assumption.
2. A weaker hypothesis is inspired by the model of topological condensation based on  $\#$  (/worm-hole/ topological sum) contacts [F6].  $\#$  contact can be modelled as a  $CP_2$  type extremal with Euclidian signature of induced metric forming topological sum with the two space-time sheets having Minkowskian signature of induced metric.  $\#$  contact is thus accompanied by two light-like 3-D causal horizons at which the metric determinant vanishes. These causal horizons carry of quantum numbers and are identified as partons. If the contact is passive in the sense that it mediates only gauge fluxes, the quantum numbers of the two partons cancel

each other. This can be true also for four-momentum in the case that time orientations of the space-time sheets are opposite.

This kind of # contacts between  $k_{eff} = 129$  and  $k = 127$  space-time sheets would force effective identity of  $k = 127$  and  $k_{eff} = 129$  quarks. The implication would be that in many-sheeted sense nucleons inside nuclei would have ordinary quantum numbers whereas in single sheeted point sense they would carry quantum numbers of quark or anti-quark.

### 3 Model of strong nuclear force based on color bonds between exotic quarks

In this section the color bond model of strong nuclear force is developed in more detail.

#### 3.1 A model for color bonds in terms of color flux tubes

##### 3.1.1 Simple model for color bond

Consider next a simple model for color bond.

1. The first guess would be that the color bond has quantum numbers of neutral pion so that also the pair of nucleons connected by a color bond would behave like a pion. This gives attractive color magnetic interaction energy and an attractive identification is as p-n bond.
2. Also the bonds with identical spins and identical color charges at the ends of the bond yield an attractive color magnetic spin-spin interaction energy. This kind of bonds would be responsible for p-p and n-n pairing. In this case color magnetic energy is however by a factor 1/3 smaller and could explain the non-existence of pp and nn bound states. An even number of neutral  $\rho$  type bonds could be allowed without anomalous contribution to the spin. High spin nuclei could contain many  $\rho$  type bonds so that antimatter would play important role in the physics of heavy nuclei.
3. A further generalization by allowing also electromagnetically charged color bonds with em quantum numbers of pion and  $\rho$  would explain tetra-neutron [34, 35] as alpha particle (pnpn) with two  $\pi_-$  type color bonds. This would predict a rich variety of exotic nuclei. Long color bonds connecting quark and anti-quark attached to different nucleons would also allow to understand the observation of Chris Illert [36] that the classical description of quantum tunnelling suggests that nucleons at the surface of nucleus have charges which are fractional.

This picture would suggest that the color isospin of the quark at the end of the bond equals to the weak isospin of the nucleon and is also identifiable as the strong isospin of the nucleon inside nucleus. To achieve an overall color neutrality the presence a dark gluon condensate compensating for the net color charge of colored bonds must be assumed. This could also compensate the net spin of the colored bonds.

The surplus of neutrons in nuclei would tend to create a non-vanishing color isospin which could be cancelled by the dark gluon condensate. The results of RHIC experiment [33] can be understood in TGD framework as a generation of a highly tangled string like structure containing large number of p-p and n-n type bonds and thus also dark gluon condensate neutralizing the net color charge. This would suggest that in a good approximation the nuclei could be seen as tangled string like structures formed from protons and neutrons. If the distances between nuclei are indeed what standard nuclear physics suggests, kind of nuclear strings would be in question.

### 3.1.2 Simple model for color magnetic flux tubes

Color magnetic flux tubes carrying also color electric fields would define the color magnetic body of the nucleus having size of order  $L(129)$ . Dark quarks would have also weak and electromagnetic field bodies with sizes  $L(111)$  and  $L(135)$ . The color magnetic body codes information about nucleus itself but also has independent degrees of freedom, in particular those associated with linking and knotting of the flux tubes (braiding plays a key role in the models of topological quantum computation [E9]).

Color flux tubes carry a non-trivial color magnetic flux and one can wonder whether the color flux tubes can end of whether they form closed circuits. Since  $CP_2$  geometry allows homological magnetic charges, color magnetic flux tubes could have ends with quarks and anti-quark at them acting as sources of the color magnetic field. The model for binding energies however favors closed strings. In the general case the color magnetic flux tubes would have a complex sub-manifold of  $CP_2$  with boundary as a  $CP_2$  projection.

The spin-spin interaction energies depend crucially on the value of the color magnetic field strength experienced by the exotic quark at the end of color flux tube, and one can at least try make educated guesses about it. The conservation of the color magnetic flux gives the condition  $g_s B \propto 1/S$ , where  $S$  is the area of the cross section of the tube.  $S \geq L^2(107)$  is the first guess for the area if valence quarks are ordinary.  $S \geq L^2(k_{eff} = 129)$  is the natural guess if valence quarks are dark.

The quantization of the color magnetic flux using the scaled up value of  $\hbar$  would give  $\int g_s B dS = n/v_0$  implying  $g_s B \simeq n/v_0 S$ . When applied to  $S \sim L^2(107)$  the quantization condition would give quite too large estimate for the spin-spin interaction energy. For  $S \sim L^2(129)$  the scale of the interaction energy would come out correctly. For  $k = 127$  option  $S \sim L^2(127)$  is forced by the quantization condition.

This observation favors strongly dark valence quarks for both options. The magnetic flux of exotic quarks would be feeded to flux tubes of transverse area  $\sim L^2(k)$ ,  $k = 127$  or  $k = 129$ , coupling naturally with the color magnetic flux tubes of valence quarks with size  $L(129)$ .

A further constraint could come from the requirement that the flux tubes is such that locally the magnetic field looks like a dipole field. This would mean that the flux tube would become thicker at larger distances roughly as  $S(r) \propto r^3$ . An alternative restriction would come from the requirement that the energy of the color magnetic flux tube is same irrespective of its cross section at dark quark position. This would give  $S \propto L$  where  $L$  is the length of the flux tube.

### 3.1.3 Quantum classical correspondence requires color bonds

Non-vacuum extremals are always accompanied by a non-vanishing classical electro-weak and color gauge fields. This is an obvious challenge for quantum classical correspondence. The presence of a suitable configuration of color bonds with dark quarks at their ends starting from nucleon gives hopes of resolving this interpretational problem. Dark quarks and anti-quarks would serve as sources of the color and weak electric gauge fluxes and quarks and nucleons would create the classical em field.

The requirement that classical Abelian gauge fluxes are equal to the quantum charges would pose very strong conditions on the physical states. For instance, quantization condition for Weinberg angle is expected to appear. The fact that classical fluxes are inversely proportional to the inverse of the corresponding gauge coupling strength  $1/\alpha_i$  gives additional flexibility and with a proper choice of gauge coupling strengths the conditions might be satisfied and space-time description would also code for the values of gauge coupling strengths. Color bonds should be present in all length scales for non-vacuum extremals encouraging the hypothesis about the p-adic hierarchy of dark QCD type phases.

### 3.1.4 Identification of dark quarks and valence quarks as identical fermions forces the organization of nucleons to nuclear strings?

Quantum classical correspondence in strong form gives strong constraints on the construction. The model explaining the nuclear binding energies per nucleon strongly favors the option in which nucleons arrange to form closed nuclear strings. If dark quarks and ordinary valence quarks can be regarded as identical fermions this hypothesis follows as a prediction. Therefore this hypothesis, which admittedly looks ad hoc and might make sense only effectively (see the discussion below), deserves a detailed consideration.

Fermi statistics implies that the quark at the end of the color bond must be in a spin state which is different from the spin state of the nucleon (spin of d quark in the case of p=uud and u quark in the case of n) to allow local S-wave. For anti-quarks there are no constraints. Only d (u) quark with spin opposite to that of p (n) can be associated with p (n) end of the color bond. Hence at most five different bonds can begin from a given nucleon. In the case of proton  $p_1$  they are given by  $d_1\bar{d}_1, \bar{q}_1q_1, q = u, d$ .

Only two bonds between given nuclei are possible as following examples demonstrate.

1.  $p_1 - n_1: d_1\bar{d}_1, \bar{u}_1u_1$ .
2.  $p_1 - p_1: d_1\bar{d}_1, \bar{d}_1d_1$ .

The experimentation with the rules in case of neutral color bonds supports the view that although branchings are possible, they do not allow more than  $A = Z + N$  bonds. One example is 6 nucleon state with p at center connected by 5 bonds to p+ 4n at periphery and an additional bond connecting peripheral p and n. This kind of configuration could be considered as one possible configuration in the case of  ${}^6\text{Li}$  and  ${}^6\text{He}$ . It would seem that there is always a closed string structure with  $A$  bonds maximizing the color magnetic binding energy. The allowance of also charged color bonds makes possible to understand tetra-neutron as alpha particle with two charged color bonds.

The fact that neutron number for nuclei tends to be larger than proton number implies that the number of n-n type  $\rho$  bonds for stringy configurations is higher than p-p type bonds so that net color isospin equal equal to  $I_3 = -(A - 2Z)$  is generated in case of stringy nuclei and is most naturally cancelled by a dark gluon condensate. Neutralizing gluon condensate allows neutron halo with a non-vanishing value of  $I_3$ .

## 3.2 About the energetics of color bonds

To build a more quantitative picture about the anatomy of the color bond it is necessary to consider its energetics. The assumption that in lowest order in  $\hbar$  the binding energy transforms as rest energy under the p-adic scaling and scaling of  $\hbar$  makes it easy to make order of magnitude estimates by scaling from the hadronic case.

### 3.2.1 Color field energy of the bond

At the microscopic level the harmonic oscillator description should correspond to the color energy associated with color bonds having u or d type quark and corresponding anti-quarks at their ends. For simplicity restrict the consideration in the sequel to electromagnetically neutral color bonds.

Besides spin-spin interaction energy and color Coulombic interaction energy there are contributions of color fields coded by the string tension  $T_d = v_0T$  of the color bond, where  $T \simeq 1/\text{GeV}^2$  is hadronic string tension. The energy of string with given length remains invariant in the combined scaling of  $\hbar$ , string tension, and length  $L$  of the color bond represented by color magnetic flux tube (which contain also color electric fields).

1. The mass of the color bonds between valence quarks assumed to have  $\hbar_s = \hbar/v_0$  of length  $L = xL(129)$  are given by  $M(107) \sim x \times \hbar/L(107) \sim x \times .5 \text{ GeV}$  and correspond naturally to the energy scale of hadronic strong interactions.
2. The rest energy of the color bonds between  $k = 127$  quarks with ordinary value of  $\hbar$  having length  $L = xL(127)$  are given by  $M(127) \sim x \times \hbar/L(127) = 2^{-10}M(107)$  so that the order of magnitude is  $x \times .5 \text{ MeV}$ .
3. The rest energy of the color bonds between  $k_{eff} = 129$  dark quarks with  $c_{\#} = v_0c$  is given by the same expression. Note however that rest mass would be scaled up by a factor  $1/v_0$ .

The resulting picture seems to be in a dramatic conflict with the electromagnetic size of nucleus which favors the  $L \sim L(107) < 2 \text{ fm}$  rather than  $L \sim L(129)$  and which is smaller by a factor  $2^{-11}$  and which favors also the notion of nuclear string. The resolution of the paradox is based on the notion of color magnetic body. Color bonds behave like color magnetic dipoles and bonds correspond to flux tubes of a topologically quantized dipole type color magnetic field having length of order  $L(129) \simeq 5 \times 10^{-12} \text{ m}$  connecting nucleons at distance  $L < L(107)$ .

### 3.2.2 Color magnetic spin-spin interaction energy, the structure of color bonds, and the size scale of the nucleus

Color magnetic spin-spin interaction allows to understand  $\rho - \pi$  mass splitting in terms of color magnetic spin-spin interaction expected to give the dominating contribution to the nuclear binding energy. The quantitative formulation of this idea requiring consistency with p-adic mass calculations and with existing view about typical electromagnetic nuclear size scale fixed by the height of Coulomb wall leads to a rather unique picture about color magnetic bonds.

#### 1. Questions

One can pose several questions helping to develop a detailed model for the structure of the color bond.

1. The contributions  $k = 113$  and  $k = 107$  space-time sheets to the mass squared are of same order of magnitude [F4]. The contributions to the mass squared add coherently inside a given space-time sheet. This requires that nucleonic space-time sheet are not directly connected by join along boundaries bonds and the assumption that color bond connect dark quarks is consistent with this. This means that it makes sense to estimate contributions to the mass squared at single nucleon level.
2. The contribution of color magnetic spin-spin interaction to the mass squared of nucleon can be regarded as coming from  $k = 107$  space-time sheets as p-adic contribution but with a large value of  $\hbar$ . If  $k = 107$  contribution would vanish, only a positive contribution to mass would be possible since the real counterpart  $\Delta m_R^2$  of p-adic  $\Delta m^2$  is always positive whereas  $(m^2 + \Delta m^2)_R < m_R^2$  can hold true.
3. What has been said about color magnetic body and color bonds applies also to electromagnetic field body characterized by  $k = 113$ . The usual electromagnetic size of nucleus is defined by the relative distances of nucleons in  $M^4$  can be much smaller than  $L(113)$  so that the prediction for Coulomb wall is not reduced to the Coulomb potential at distance  $L(113)$ . Nucleon mass could be seen as due to p-adic thermodynamics for mass squared (or rather, conformal weight) with the real counterpart of the temperature being determined by p-adic length scale  $L(113)$ .

4. The model inspired by p-adic mass calculations [F4] forced the conclusion that valence quarks have join along boundaries bonds between  $k = 107$  and  $k = 113$  space-time sheets possibly feeding color fluxes so that closed flux loops between the two space-time sheets result. The counter intuitive conclusion was that roughly half of quark mass is contributed by the  $k = 113$  space-time sheet which is by a scale factor 8 larger than the color size of quarks. If valence quarks are dark, scaled up  $k = 107$  space-time sheet having  $k_{eff} = 129$  becomes the larger space-time sheet, and the situation would not look so counter-intuitive anymore.
5. How the ends of the color bonds are attached to the  $k = 113$  nucleon space-time sheets? The simplest assumption is that color bonds correspond to color magnetic flux tubes of length scale  $L(129)$  starting at or being closely associated with  $k = 107$  space-time sheets of nucleons. Hence the contribution to the mass squared would come from scaled up  $k_{eff} = 129$  space-time sheet and add coherently to the dominating p-adic  $k = 107$  contribution to the mass squared of nucleon.
6. If exotic quarks are  $k = 127$  quarks with ordinary value of  $\hbar$ , one encounters the problem how their contributions can add coherently with  $k_{eff} = 129$  color contribution to reduce the rest energy of nucleus. One possibility allowed by the appearance of harmonics of  $v_0$  is that  $\hbar$  is scaled up by  $1/(2v_0) \simeq 2^{10}$  so that space-time sheets have same size or that p-adic additivity of mass squared is possible for effective p-adic topologies which do not differ too much from each other.

## 2. Estimate for color magnetic spin-spin interaction energy

Suppose the scaling invariance in the sense that the binding energies transform in the lowest order just like rest masses so that one can estimate the color magnetic spin-spin splittings from the corresponding splittings for hadrons without any detailed modelling. This hypothesis is very attractive predicts for both options that the scale of color magnetic spin-spin splitting is  $2^{-n}$  times lower than for  $\pi - rho$  system, where  $n = 10$  for  $n = 127$  option and  $n = 11$  for  $k_{eff} = 129$  option. For scaled down spin-spin interaction energy for  $\pi$  type bond is  $E \sim .4$  MeV for  $k = 127$  and  $\sim .2$  MeV for  $k_{eff} = 11$ , which would mean that the bond is shorter than scaled up length  $L(\pi)$  of color bond between valence quarks of pion.

The further assumption that color magnetic spin-spin interaction energy behaves as  $\alpha_s/m_q^2 L^3$ ,  $L = x2^n L(\pi)$ . This gives  $E \simeq x^{-3}2^{-n} E(107)$ . The value of  $x$  can be estimated from the requirement that the energy is of order few MeV. This gives  $x \sim 10^{-1/3}$  for  $k = 127$  option and  $x \sim (20)^{-1/3}$  for  $k_{eff} = 129$  option.

## 4 How the color bond model relates to the ordinary description of nuclear strong interactions?

How the notion of strong isospin emerges from the color bond model? What about shell model description based on harmonic oscillator potential? Does the model predict spin-orbit interaction? Is it possible to understand the general behavior of the nuclear binding energies, in particular the anomalously small binding energies of light nuclei? What about magic numbers? The following discussion tries to answer these questions.

### 4.1 How strong isospin emerges?

The notion of strong isospin is a crucial piece of standard nuclear physics. Could it emerge naturally in the transition to the phase involving dark quarks? Could the transition to color confined phase

mean a reduction of color group as isotropy group of  $CP_2$  type extremals representing elementary particles to  $U(2)$  identifiable as strong isospin group. Could  $U(1)_Y \times U(1)_{I_3}$  or  $U(1)_{I_3}$  be identifiable as the Abelian holonomy group of the classical color field responsible for the selection of a preferred direction of strong isospin?

This picture would not mean breaking of the color symmetry at the configuration space level where it would rotate space-time surfaces in  $CP_2$  like rigid bodies. Rather, the breaking would be analogous to the breaking of rotational symmetry of individual particles by particle interactions. Strong isospin would correspond to the isotropy group of the space-time surface and the preferred quantization direction to the holonomy group of the induced color gauge field. The topological condensation of quarks and gluons at hadronic and nuclear space-time surfaces would freeze the color rotational degrees of freedom apart from isotropies providing thus the appropriate description for the reduced color symmetries.

#### 4.1.1 Mathematical support for the picture from classical TGD

There is mathematical support for the proposed view and closely relating to the long-standing interpretational problems of TGD.

1.  $CP_2$  holonomy group is identifiable as  $U(2)$  subgroup of color group and well as electro-weak gauge group. Hitherto the possible physical meaning of this connection has remained poorly understood.  $U(2)$  subgroup as isotropies of space-time surfaces with  $D = 2$ -dimensional  $CP_2$  projection, which belongs to a homologically non-trivial geodesic sphere  $S^2$ , and defines a sub-theory for which all induced gauge fields are Abelian and a natural selection of a preferred strong isospin direction occurs. Thus one might identify strong isospin symmetry as the  $SU(2)$  subgroup of color group acting as the isotropy group of the space-time surface and strong isospin would not correspond to the group of isometries but to space-time isotropies.
2. Color isospin component of gluon field, em field and  $Z^0$  field which corresponds to weak isospin, are proportional to each other for solutions having 2-dimensional  $CP_2$  projection. In fact, both  $Z^0$  and  $I_3$  component of gluon field are proportional to the induced Kähler form with a positive coefficient. If the proposed quantum classical correspondence for color bonds holds true, this means that the signs of these charges are indeed correlated also for nucleon and quark/ anti-quark. The ratios of these charges are fixed for the extremals for which  $CP_2$  projection is homologically non-trivial geodesic sphere  $S^2$ .
3. It is far from clear whether the classical  $Z^0$  field can vanish for any non-vacuum extremals. If this is not the case, dark weak bosons would be unavoidable and strong isospin could be identifiable as color isospin and dark weak isospin. The predicted parity breaking effects need not be easily detectable since dark quarks would be indeed dark matter. An open question is whether some kind of duality holds true in the sense that either color field or vectorial part of  $Z^0$  field could be used to describe the nuclear interaction. This duality brings in mind the  $SO(4) \leftrightarrow SU(3)$  duality motivated by the number theoretical vision [A1, A2, A3, E2].
4. The minimal form of the quantum classical correspondence is that at least the signs of the  $I_3$  and  $Y$  components of the color electric flux correlate with the dark quark at the end of color bond and the signs of the  $Z^0$  field and Kähler field correlate with the sign of weak isospin and weak hyper-charge of nucleon. A stronger condition is that these classical gauge fluxes are identical with a proper choice of the values of gauge coupling strengths and that in the case of color fluxes the quark at the end of the bond determines the color gauge fluxes in the bond whereas electromagnetic would distribute freely between the bonds.

### 4.1.2 Correlation between weak isospin and color isospin

The weakest assumption motivated by this picture would be that the sign of color isospin correlates with the sign of weak isospin so that the quarks at the ends of color bonds starting from nucleon would have color isospin equal to the weak isospin of the nucleon:

$$I_{3,s} = I_{3,w} = I_{3,c} \ .$$

This assumption would allow to interpret the attractive strong interaction between nucleons in terms of color magnetic interaction. p-n bond would be neutral  $\pi_0$  type color singlet bonds. n-n and p-p bonds would have spin  $\pm 1$  and color isospin equal to strong iso-spin of  $\rho_{\pm}$ . Note that QCD type color singlet states invariant under  $I_3 \rightarrow -I_3$  would not be possible. Color magnetic interaction mediated by the pion type color bond would be attractive for p and n since color isospins would be opposite sign but repulsive for pp and nn since color isospins would have same sign. The  $\rho$  type color bond with identical spins and color isospins  $I_3$  would generate attractive interaction between identical nucleons. The color magnetic spin-spin interaction energy would be 3 times larger for  $\pi$  type bond so that the formation of deuterium as bound state of p and n and absence of pp and nn bound states might be understood.

It is not possible to exclude charged color bonds, and as will be found, their presence provides an elegant explanation for tetra-neutron [34, 35].

## 4.2 How to understand the emergence of harmonic oscillator potential and spin-orbit interaction?

Shell model based on harmonic oscillator potential and spin-orbit interaction provide rather satisfactory model of nuclei explaining among other things magic numbers.

### 4.2.1 Harmonic oscillator potential as a phenomenological description

It would be a mistake to interpret nuclear harmonic oscillator potential in terms Coulomb potential for the  $I_3$  component of the classical gluon field having color isospin as its source. Interaction energy would have correct sign only for proton+quark/ anti-quark or neutron+quark/ anti-quark at the end of the color bond so that only neutrons or protons would experience an attractive force.

Rather, the harmonic oscillator potential codes for the presence of color Coulombic and color magnetic interaction energies and is thus only a phenomenological notion. Harmonic oscillator potential emerges indeed naturally since the nucleus can be regarded as a collection of nucleons connected by color flux tubes acting rather literally as strings. The expansion the interaction energy around equilibrium position naturally gives a collection of harmonic oscillators. The average force experience by a nucleon is expected to be radial and this justifies the introduction of external harmonic oscillator potential depending on  $A$  via the oscillator frequency.

At the deeper level the system could be seen as a tangle formed by bosonic strings represented by magnetic flux tubes connecting  $k = 111$  space-time sheets containing dark quarks closely associated with nucleons. The oscillations of nucleons in harmonic oscillator potential induce the motion of dark quark space-time sheets play the role of branes in turn inducing motion of the ends of flux tubes fix the boundary values for the vibrations of the flux tubes. The average force experienced by nucleons around equilibrium configuration is expected to define radial harmonic force. This holds true even in the case of nuclear string.

In this picture  $k = 111$  space-time sheets could contain the nucleons of even heaviest nuclei if the nucleon size is taken to be  $2L(107)/3 \simeq 1.5$  fm. The prediction for the highest possible mass number without neutron halo, which is at radius  $2.5 \times L(111)$ , would be  $A = 296$  assuming that nuclear radius is  $R = 1.4$  fm.  $A = 298$  is the mass number of the heaviest known superheavy nucleus [30] so that the prediction can be regarded as a victory of the model.



### 4.2.2 Could conformal invariance play a key role in nuclear physics?

The behavior the binding energies of  $A \leq 4$  nucleons strongly suggest that nucleons are arranged to closed string like structure and have thus only two color bonds to the neighboring nucleons in the nuclear string. The thickness of the string at the positions of fermions defines the length scale cutoff defining the minimal volume taken by a single localized fermion characterized by given p-adic prime.

The conformal invariance for the sections of the string defined by color bonds is should allow a deeper formulation of the model in terms of conformal field theory. The harmonic oscillator spectrum for single particle states could be interpreted in terms of stringy mass squared formula  $M^2 = M_0^2 + m_1^2 n$  which gives in good approximation

$$M = m_0 + \frac{m_1^2}{2M_0} n . \quad (1)$$

The force constant would be determined by  $M_0$  which would be equal to nucleon mass.

Presumably this would bring to the mind of M-theorist nucleus as a system of  $A$  branes connected by strings. The restriction of the wave functional of the string consisting of portions connecting nucleons to each other at the junction points would be induced by the wave functions of nucleons. The bosonic excitations of the color magnetic strings would contribute to color magnetic energy of the string characterized by its string tension. This energy scale might be considerably smaller than the fermionic energy scale determined by the color magnetic spin-spin interaction.

### 4.2.3 Dark color force as the origin of spin-orbit interaction

The deviation of the magic numbers associated with protons ( $Z = 2, 8, 20, 28, 40, 82$ ) and neutrons ( $A - Z = 2, 8, 20, 28, 50, 82, 126$ ) from the predictions of harmonic oscillator model provided the motivation for the introduction of the spin orbit interaction  $V_{L-S}$  [17] with the following general form

$$V_{L-S}(r) = \bar{L} \cdot \bar{S} \frac{1}{r} \left( \frac{dV_s}{dr} + \frac{dV_I}{dr} \bar{\tau}_1 \cdot \bar{\tau}_2 \right) . \quad (2)$$

The interaction implies the splitting of  $(j, l, s)$  eigen states so that states  $j, l = j \pm \frac{1}{2}$  have different energies. If the energy splitting is large enough, some states belonging to a higher shell come down and combine with the states of the lower shell to form a new shell with a larger magic number. This is what should happen for both proton and neutron single particle states.

The origin of spin-orbit interaction would be the classical color field created by the color isospin in p-p and n-n color bonds and dark gluons compensating the color charge. Spin-orbit interaction results in the atomic physics context from the motion of electrons in the electric field of the nucleus. The moving particle experiences in its rest frame a magnetic field  $\bar{B} = \bar{v} \times \bar{E}$ , which in the spherically symmetric case can by little manipulations can be cast into the form

$$\bar{B} = \frac{\bar{p}}{m} \times \frac{\bar{r}}{r} \frac{dV}{dr} = \bar{L} \frac{1}{m} \frac{1}{r} \frac{dV}{dr} .$$

The interaction energy is given by

$$E = -\bar{\mu} \cdot \bar{B} = -\frac{ge}{2m^2} \bar{S} \cdot \bar{L} \times \frac{1}{r} \frac{dV}{dr} . \quad (3)$$

Here magnetic moment is expressed in terms of spin using the standard definitions.  $g$  denotes Lande factor and equals in good approximation to  $g = 2$  for point like fermion.

Classical color field can be assumed to contain only  $I_3$  component and be derivable from spherically symmetric potential. In the recent case the color bonds moving made from two quarks and moving with nuclear string experience the force.

The color magnetic moments of the quark and anti-quark are of same sign in for both  $\rho$  and  $\pi$  type bond so that the isospin component of the net color magnetic moment can be written as

$$\bar{\mu}_c = g \frac{g_s}{m_q(\text{dark})} I_3 \bar{S} . \quad (4)$$

Here  $g_s$  denotes color coupling constant,  $g$  is the Lander factor equal to  $g = 2$  in ideal case, and  $m$  is mass parameter. Since the color bond is color magnetic flux tube attached from its ends to dark quarks it seems that the mass parameter  $m_q(\text{dark})$  in the magnetic moment is that of dark quark and should be  $m_q(\text{dark}) = v_0 m_q$ .

An additional factor of 2 is present because both quark and anti-quark of the bond give same contribution to the color moment of the bond.  $I_3$  equals to the strong isospin of the nucleon to which the quark is attached and spin is opposite to the spin of this quark so that a complete correlation with the quantum numbers of the second nucleon results and one can effectively assign the spin orbit interaction with nucleons. The net interaction energy is small for spin paired states. The sign of the interaction is same for both neutrons and protons.

Using the general form of the spin orbit interaction potential in the non-relativistic limit, one can cast the  $L - S$  interaction term in a the form

$$V_{L-S}(r) = \frac{16\pi\mu_c}{m_q(\text{dark})} \bar{L} \cdot \bar{S} \frac{1}{r} \frac{dV_{I_3}}{dr} . \quad (5)$$

In the first order perturbation theory the energy change for  $(j, l, s)$  eigen state with  $l = j + \epsilon \frac{1}{2}$ ,  $\epsilon = \pm 1$  and spherically symmetric electromagnetic gauge potential  $V(r)$  [21] given by

$$\begin{aligned} \Delta E(j, l = j + \epsilon \frac{1}{2}) &= \frac{4g_s^2}{m_q^2(\text{dark})L^3} (N - P)c(l) \left[ \epsilon(j + \frac{1}{2}) + 1 \right] , \\ c(l) &= -\frac{4\pi L^3}{g_s(N - P)} \langle l | \frac{1}{r} \frac{dV_{I_3}}{dr} | l \rangle . \end{aligned} \quad (6)$$

The coefficient  $g_s/4\pi$  and factor  $N - P$  have been extracted from the color gauge potential in the expression of  $a(l)$  to get a more kinematical expression.  $N - P$ -proportionality is expected since the system has net nuclear color isospin proportional to  $N - P$  neutralized by dark gluons which can be thought of as creating the potential in which the nuclear string moves. The constant  $c(l)$  contains information about the detailed distribution of the color isospin.  $c(l)$  depends also on the details of the model (the behavior of single particle radial wave function  $R_{n,l}(r)$  in case of wave mechanical model and now on its analog defined by the wave function of nucleon induced by nuclear string).  $R$  denotes the nuclear charge radius.

The general order of magnitude of  $L$  is  $L \sim L(129)$ . What comes in mind first is the scaling  $L \sim v_0^{-1} R_0$ ,  $R_0 \sim (3/5) \times L(107) \simeq 1.5 \times 10^{-15}$  m. This is not consistent with the fact that for light nuclei with  $A \leq 4$   $L$  decreases with  $A$  but conforms with the fact that spin-spin interaction energies which are very sensitive to  $L$  can depend only slightly on  $A$  so that  $L$  must be more or less independent on  $A$ . Assume  $g_s^2/4\pi = .1$  and  $m_q = m_u \sim .1$  GeV,  $g = 1$  in the formula for the color magnetic moment. By using  $2\pi/L(107) \simeq .5$  GeV these assumptions lead to the estimate

$$\begin{aligned}
\Delta E(j, l = j + \epsilon \frac{1}{2}) &= \frac{4g_s^2}{m_q^2 L^3 (107)} \left(\frac{5}{3}\right)^3 \times v_0 \times (N - P) \times c(l) \times \left[ \epsilon(j + \frac{1}{2}) + 1 \right] \\
&\simeq (\epsilon(j + \frac{1}{2}) + 1) \times (N - P) \times c(l) \times 2.9 \text{ MeV} .
\end{aligned}
\tag{7}$$

The splitting is predicted to be same for protons and neutrons and also the magnitude looks reasonable. If the dark gluons are at the center and create a potential which is gradually screened by the dark quark pairs, the sign of the spin-orbit interaction term is correct meaning that the contribution to binding energy is positive for  $j + 1/2$  state. In the case of neutron halo the unscreened remainder of the dark gluon color charge would define  $1/r$  potential at the halo possibly responsible for the stability.

This estimate should be compared to the general estimate for the energy scale in the harmonic oscillator model given by  $\omega_0 \simeq 41 \cdot A^{-1/3}$  MeV [17] so that the general orders of magnitude make sense.

### 4.3 Binding energies and stability of light nuclei

Some examples are in order to see whether the proposed picture might have something to do with reality.

#### 4.3.1 Binding energies of light nuclei

The estimate for the binding energies of light nuclei is based on the following assumptions.

1. Neglect the contribution of the string tension and dark gluon condensate to the binding energy.
2. Suppose that the number of bonds equals to  $A$  for  $A \leq 4$  nuclei and that the the bonds are arranged to maximize color magnetic spin-spin interaction energy. A possible interpretation is in terms of a closed color magnetic flux tube connecting nucleons. The presence of close color magnetic flux tubes is necessary unless one allows homological color magnetic monopoles. This option favors the maximization of the number of n-p type bonds since their spin-spin interaction energy is 3 times higher than that for p-p and n-n type bonds. This is just a working hypothesis and would mean that nuclei could be seen as nuclear strings.

The alternative interpretation is that the number bonds per nucleon is constant so that the binding energy would not depend on nucleon. The number of bonds could be quite large. Scaling the c quark mass of about 4 GeV gives gives dark mass of about 2 MeV so that two dark generations might be possible. For two dark quark generations 8+8 different quarks can appear at the ends of color flux tubes and 64 different color bonds are in principle possible (which brings in mind the idea of nuclear genetic code and TGD proposal for quantum computation utilizing braided flux tubes!). Also in this case the bond energy can depend on whether  $p$  or  $n$  is question for  $P \neq N$  nuclei since p-p and n-n bonds have smaller bind energy than p-n type bonds.

3. Assume that the nucleons are topologically condensed at  $k = 111$  space-time sheet with zero point kinetic energy

$$E_0(A) \sim \frac{3n}{2} \frac{\pi^2}{Am_p L^2(111)} \equiv \frac{n}{A} \times E_0(A = 1) ,$$

where  $n$  is a numerical factor and  $E_0(A = 1) \simeq 23$  MeV. Let  $\Delta E$  denote the color magnetic spin-spin interaction energy per nucleon for  $\pi$  type bond. The zero point kinetic energy is largest for  $A \leq 3$  and explains why the binding energy is so small. For  $n = 1$  the zero point kinetic energy would be 5.8 MeV for  $A = 4$ , 7.7 MeV for  $A = 3$ , and 11.5 MeV for  $A = 2$ .

With these assumptions the binding energy per bond can be written for  $A \leq 4$  as

$$E = r \times \Delta E - \frac{nE_0(p)}{A^2} ,$$

where  $\Delta$  denotes the color magnetic spin-spin interaction energy per bond. The parameter  $r$  codes for the fact that color magnetic spin-spin interaction energy depends on whether p-p or n-n type bond is in question. The values of  $r$  are  $r(^4He) = 1, r(^3He) = 7/9, r(^2H) = 1$ .

Estimates for  $n$  and  $\Delta$  can be deduced from the binding energies of  $^2H$  and  $^3He$ . The result is  $n = 1.0296$  and  $\Delta E = 7.03$  MeV. The prediction for  $^4He$  binding energy is 6.71 MeV which is slightly smaller than the actual energy 7.07 MeV. The value of the binding energy per nucleon is in the range 7.4-8.8 MeV for heavier nuclei which compares favorably with the prediction 7.66 MeV at the limit  $A \rightarrow \infty$ . The generation of dark gluon condensate and color Coulombic energy per nucleon increasing with the number of nucleons could explain the discrepancy.

(A,Z)	(2,1)	(3,1)	(3,2)	(4,2)
$E_B/MeV$	1.111	2.826	2.572	7.0720

Table 1. The binding energies per nucleon for the lightest nuclei.

#### 4.3.2 Why certain light nuclei do not exist?

The model should also explain why some light nuclei do not exist. In the case of proton rich nuclei electromagnetic Coulomb interaction acts as un-stabilizer. For heavy nuclei with non-vanishing value of  $P - N$  the positive contribution of dark gluons to the energy tends to in-stabilize the nuclei. The color Coulombic interaction energy is expected to behave as  $(N - P)^2$  whereas the energy of dark gluons behaves as  $|N - P|$ . Hence one expects that for some critical value of  $|N - P|$  color Coulombic interaction is able to compensate the contribution of dark gluon energy. One the other hand, the larger number of nn type bonds tends reduced the color magnetic spin-spin interaction energy.

1. Coulomb repulsion for pp is estimated to be .76 MeV from  $^3He - ^3H$  mass difference whereas the color magnetic binding energy would be  $E_D/3 = .74$  MeV from the fact that the energy of  $\rho$  type bond is 1/3 from that for  $\pi$  type bond. Hence pp bound state would not be possible. The fact that nn bound state does not exist, suggests that the energy of the color neutralizing dark gluon overcomes the color Coulombic interaction energy of dark gluon and dark quarks and spin-spin interaction energy of  $\rho_0$  type bond.
2. For ppp and nnn protons cannot be in S wave. The color magnetic bond energy per nucleon would be predicted to be  $E_D = 2.233$  MeV whereas a rough order of magnitude estimate for Coulombic repulsion as

$$E_{em} = Z(Z - 1) \times [E_B(^3H) - E_B(^3He)] = Z(Z - 1) \times .76 \text{ MeV}$$

gives  $E_{em} \simeq 4.56$  MeV so that ppp bound state is not possible. nnn bound state would not be possible because three dark gluons would not be able to create high enough color Coulomb interaction energy  $E_c$  which together with color magnetic spin-spin interaction energy  $E_D$  would compensate their own negative contribution  $3E_g$ :

$$3E_g > E_D + E_c .$$

3. For pppp and nnnn Fermi statistics forces two nucleons to higher partial waves so that the states are not stable. Tetraneutron need not correspond to nnnn state in TGD framework but has more natural interpretation as an alpha particle containing two negatively charged dark quark pairs.

#### 4.4 Strong correlation between proton and neutron numbers and magic numbers

The estimates for the binding energies suggest that nucleons arrange into closed nuclear strings in which nucleons are connected by long color magnetics with one dark quark anti-quark pair per nucleon. Nuclear string approach allows to understand the strong correlation between proton and neutron numbers as well as magic numbers.

##### 4.4.1 Strong correlation between $Z$ and $N$

$N = Z$  nuclei with maximal color magnetic spin-spin interaction energy arranged into closed nuclear strings contain only colored  $\pi$  type bonds between p and n and should be especially stable. The question is how to create minimum energy configurations with  $N \neq Z$ .

1. If only stringy configurations are allowed, the removal of the proton would create  $\rho$  type n-n bond and lead to a reduction of binding energy per nucleon. This would predict that  $(Z,Z)$  type isotopes correspond to maxima of binding energy per nucleon. The increase of the Coulombic energy disfavors the removal of neutrons and addition of protons.
2. For a given closed string structure one can always link any given proton by  $\bar{u}u$  bond to neutron and by  $\bar{d}d$  bonds to two protons (same for neutron). The addition of only neutron to a branch from proton gives nuclei  $(Z,N=Z+k)$ ,  $k = 1, \dots, Z$ , having only  $\pi$  type bonds. In a similar manner nuclei with  $(Z+k, Z)$ ,  $k = 1, \dots, Z$ , containing only  $\pi$  type bonds are obtained. This mechanism would predict isotopes in the ranges  $(Z,Z)$ - $(Z,2Z)$  and  $(Z,Z)$ - $(2Z,Z)$  with the same strong binding energy per nucleon apart from increase of the binding energy caused by the generation of dark gluon condensate which in the case of protons seems to be overcome by Coulomb repulsion. Very many of these isotopes are not observed so that this mechanism is not favored.

Consider how this picture compares with experimental facts.

1. Most  $Z = N$  with  $Z \leq 29$  nuclei exist and are stable against strong decays but can decay weakly. The interpretation for the absence of  $Z > 29$   $Z = N$  nuclei would be in terms of Coulomb repulsion. Binding energy per nucleon is usually maximum for  $N = Z$  or  $N = Z + 1$  for nuclei lighter than Si. The tendency  $N > Z$  for heavier nuclei could be perhaps understood in terms of the color Coulombic interaction energy of dark gluon condensate with color charges in n-n type color bonds. This would allow also to understand why for  $Z = 20$  all isotopes with  $(Z = 20, N > 20)$  have higher binding energy per nucleon than  $(Z = 20, N = 20)$  isotope in conflict with the idea that doubly magic nucleus should have a maximal binding energy.

The addition of neutrons to  $^{40}\text{Ca}$  nucleus, besides increasing the binding energy per nucleon, also decreases the charge radius of the nucleus contrary to the expectation that the radius of the nucleus should be proportional to  $A^{1/3}$  [17]. A possible interpretation is in terms of the color Coulombic interaction energy due to the generation of dark gluon condensate, the presence of which reduces the equilibrium charge radius of the nucleus.

2.  ${}^8\text{Be}$  having  $(Z, N) = (4, 4)$  decaying by alpha emission (to two alpha particles) is an exception to the rule. The binding energy per nucleon 7.0603 MeV of Be is slightly lower than the binding energy 7.0720 MeV of alpha particle and the pinching of the Be string to form two alpha strings could be a possible topological decay mechanism.

#### 4.4.2 Magic nuclei in shell model and TGD context

Spin-spin pairing for identical nucleons in the harmonic oscillator potential is an essential element of the harmonic oscillator model explaining among other things shell structure and lowest magic numbers 2, 8, 20 but failing for higher magic numbers 28, 50, 82, 126 (the prediction is 2,8,20 and 40, 68, 82, 122). Spin-orbit coupling [28] reproduces effectively the desired shell structure by drawing some states of the higher shell to the lower shell, and it is indeed possible to reproduce the magic numbers in this manner for 3-D harmonic oscillator model.

This picture works nicely if magic nuclei are identified as nuclei which have exceptionally high abundances.  ${}^{28}\text{Fe}$ , the most abundant element, is however an exception to the rule since neither  $Z$  nor  $N$  are magic in this case. The standard explanation for the stable nuclei of this kind is as endpoints of radioactive series. This explanation does not however remove the problem of understanding their large binding energy, which is after all what matters.

The surprise of recent years has been that even for neutron rich unstable nuclei 28 appears as a magic number for unstable neutrons in very neutron rich nuclei such as  $\text{Si}(14,28)$  [29] so that the notion of magic number does not seem to be so dependent on spin-orbit interactions with the nuclear environment as believed. Also new magic numbers such as  $N=14,16,30,32$  have been discovered in the neutron sector [29]. Already the stable isotope  $\text{Mg}(12,14)$  has larger binding energy per nucleon than doubly magic  $\text{Mg}(12,12)$  and could be perhaps understood in terms of dark gluons.  ${}^{56}\text{Fe}$  and  ${}^{58}\text{Fe}$  correspond to  $N=30$  and  $32$ . The linking of two  $N=8$  magic nuclei would give  $N=16$  and various linkings of  $N=14$  and  $N=16$  nuclei would reduce the stability  $N = 28, 30, 32$  magic nuclei to the stability of their building blocks. Perhaps these findings could provide motivations for considering whether the stringy picture might provide an alternative approach to understanding of the magic numbers.

##### 1. The identification of magic nuclei as minima of binding energy predicts new magic numbers

The identification of the magic nuclei as minima of the binding energy as function of  $Z$  and  $N$  provides an alternative definition for magic numbers but this would predict among other things that also  $Z = N = 4, 6, 12$  also correspond to doubly magic nuclei in the sense that  $E_b({}^8\text{Be}) = 7.0603$ ,  $E_b({}^{12}\text{C}) = 7.677$  MeV and  $E_B({}^{24}\text{Mg}) = 8.2526$  are maxima for the binding energy per nucleon as a function of  $Z$  and  $N$ . For higher nuclei addition of neutrons to a doubly magic nucleus typically increases the binding energy up to some critical number of added neutrons (the generation of the dark gluon condensate would explain this in TGD framework). The maximum for the excitation energy of the first excitation seems to be the definition of magic in the shell model.

##### 2. Platonic solids and magic numbers

The TGD picture suggest that light magic nuclei could have a different, purely geometric, interpretation in terms of five regular Platonic solids.  $Z = N = 4, 6, 8, 12, 20$  could correspond to tetrahedron, octahedron (6 vertices), hexahedron (8 vertices), dodecahedron (12 vertices), and icosahedron (20) vertices. Each vertex would contain a bonded neutron and proton in the case of doubly magic nucleus. This model would predict correctly all the maxima of the binding energy per nucleon for  $Z, N \leq 20$ .

##### 3. $p$ -Adic length scale hypothesis and magic numbers

$Z = N = 8$  could be also interpreted as a maximal number of nucleons which  $k = 109$  space-time sheet associated with dark quarks can contain.  $p$ -Adic length scale hypothesis would suggest

that strings with length coming as p-adic length scale  $L(k)$  are especially stable. Strings with thickness  $L(109)$  would correspond to  $Z=N=2$  for length  $L = L(109)$ ,  $L(k = 109 + 2n)$  would correspond to  $Z = 2^{n+1}$  explaining  $N = 2, 8, 16, 32$ .

*4. Could the linking of magic nuclei produce new magic nuclei?*

Nuclear strings can become knotted and linked with fermion statistics guaranteeing that the links cannot be destroyed by a 3-dimensional topological transition.

An interesting question is whether the magic numbers  $N = 14, 16, 30, 32$  could be interpreted in terms of lower level magic numbers:  $14=8+6, 16=8+8, 30=16+14, 32=16+16$ . This would make sense if  $k = 111$  space-time sheets containing  $Z, N \leq 4, 6, 8$  neutrons and protons define basic nucleon clusters forming closed nuclear strings. The linking these structures could give rise to higher magic nuclei whose stability would reduce that of the building blocks, and it would be possible to interpret magic number  $Z, N = 28 = 20 + 8$  as linked lower level magic nuclei.

The partitions  $28=20+8, 50=20+2+28 = 20+2+8+20, 82=50+2+28, 126=50+50+20+6=82+28+8+8$  inspire the question whether higher doubly magic nuclei and their deformations could correspond to linked lower level magic nuclei so that a linking hierarchy would result.

**4.4.3 Could the transition to the electromagnetically dark matter cause the absence of higher shells?**

Spin orbit coupling explains the failure of the shell model as an explanation of the magic numbers. Transition to electromagnetic dark matter at critical charge number  $Z = 12$  suggests an alternative explanation for the failure in the case of protons. The phase transition of Pd nuclei ( $Z=46$ ) to electromagnetically dark nuclear phase inducing in turn the transition of  $D$  nuclei to dark matter phase has been proposed as an explanation for cold fusion [J6].

On basis of  $Z^2\alpha_{em} \simeq 1$  criterion  $Z = 12$  would correspond to the critical value for the nuclear charge causing this transition. One can argue that due to the Fermi statistics nuclear shells behave as weakly interacting units and the transition occurs for the first time for  $Z = 20$  nucleus, which corresponds to Ca, one of the most important ions biologically and neurophysiologically. These necessarily completely filled structures would become structural units of nuclei at electromagnetically dark level.

An alternative interpretation is that the criterion to dark matter phase applies only to a pair of two systems and reads thus  $Z_1 Z_2 \alpha_{em} \simeq 1$  implying that only the nuclei  $Z, N \geq 40$  can perform the transition to the dark phase (what this really means is an interesting question). This would explain why Pd with  $Z = 46$  has so special role in cold fusion.

Interestingly, the number of protons at  $n = 2$  shell of harmonic oscillator is  $Z = 12$  and thus corresponds to a critical value for em charge above which a transition to an electromagnetic dark matter phase increasing the size of the electromagnetic  $k = 113$  space-time sheet of nucleus by a factor  $\simeq 2^{11}$  could occur. This could explain why  $n = 2$  represents the highest allowed harmonic oscillator shell with higher level structures consisting of clusters of  $n < 3$  shells. Neutrons halos could however allow higher shells.

**4.4.4 Could only the hadronic space-time sheet be scaled up for light nuclei?**

The model discussed in this chapter is based on guess work and leaves a lot of room for different scenarios. One of them emerged only after a couple of months finishing the work with this chapter.

*1. Is only the  $\hbar$  associated with hadronic space-time sheet large?*

The surprising and poorly understood conclusion from the p-adic mass calculations was that the p-adic primes characterizing light quarks u,d,s satisfy  $k_q < 107$ , where  $k = 107$  characterizes hadronic space-time sheet [F4].

1. The interpretation of  $k = 107$  space-time sheet as a hadronic space-time sheet implies that quarks topologically condense at this space-time sheet so that  $k = 107$  cannot belong to the collection of primes characterizing quark.
2. Since hadron is expected to be larger than quark, quark space-time sheets should satisfy  $k_q < 107$  unless  $\hbar$  is large for the hadronic space-time sheet so that one has  $k_{eff} = 107 + 22 = 129$ . This would predict two kinds of hadrons. Low energy hadrons consists of u, d, and s quarks with  $k_q < 107$  so that hadronic space-time sheet must correspond to  $k_{eff} = 129$  and large value of  $\hbar$ . One can speak of confined phase. This allows also  $k = 127$  light variants of quarks appearing in the model of atomic nucleus. The hadrons consisting of c,t,b and the p-adically scaled up variants of u,d,s having  $k_q > 107$ ,  $\hbar$  has its ordinary value in accordance with the idea about asymptotic freedom and the view that the states in question correspond to short-lived resonances.

This picture is very elegant but would mean that it would be light *hadron* rather than quark which should have large  $\hbar$  and scaled up Compton length. This does not affect appreciably the model of atomic nucleus since the crucial length scales  $L(127)$  and  $L(129)$  are still present.

2. *Under what conditions quarks correspond to large  $\hbar$  phase?*

What creates worries is that the scaling up of  $k = 113$  quark space-time sheets of quarks forms an essential ingredient of condensed matter applications [F10] assuming also that these scaled up space-time sheets couple to scaled up  $k = 113$  variants of weak bosons. Thus one must ask under what conditions  $k = 113$  quarks, and more generally, all quarks can make a transition to a dark phase accompanying a simultaneous transition of hadron to a doubly dark phase.

The criterion for the transition to a large  $\hbar$  phase at the level of valence quarks would require that the criticality criterion is satisfied at  $k = 111$  space-time sheet and would be expressible as  $Z^2\alpha_{em} = 1$  or some variant of this condition discussed above.

The scaled up  $k = 127$  quark would correspond to  $k = 149$ , the thickness of the lipid layer of cell membrane. The scaled up hadron would correspond to  $k = 151$ , the thickness of cell membrane. This would mean that already the magnetic bodies of hadrons would have size of cell membrane thickness so that the formation of macroscopic quantum phases would be a necessity since the average distance between hadrons is much smaller than their Compton length.

#### 4.5 A remark about stringy description of strong reactions

If nucleons are arranged into possibly linked and knotted closed nuclear strings, nuclear reactions could be described in terms of basic string diagrams for closed nuclear strings.

The simplest fusion/fission reactions  $A_1 + A_2 \leftrightarrow (A_1 + A_2)$ ,  $A_i > 2$ , could correspond to reactions in which the  $k = 111$  dark space-time sheets fuse or decay and re-distribution of dark quarks and anti-quarks between nucleons occurs so that system can form a new nucleus or decay to a new nuclei. This also means re-organizes the linking and knotting of the color flux tubes.

The reactions  $p/n+A \rightarrow ..$  would involve the topological condensation of the nucleon to  $k = 111$  space-time sheet after which it can receive quark anti-quark pair, which can be also created by dark gluon emission followed by annihilation to a dark quark pair.

#### 4.6 Nuclear strings and DNA strands

Nuclear strings consisting of protons and neutrons bring in mind bit arrays. Their dark mirror counterparts in turn brings in mind the structure of DNA double strand. This idea does not look so weird once one fully accepts the hierarchies associated with TGD. The hierarchy of space-time sheets quantified by p-adic fractality, the hierarchy of infinite primes representable as a repeated



second quantization of a super-symmetric arithmetic quantum field theory, the self hierarchy predicted by TGD inspired theory of consciousness, the Jones inclusion hierarchy for von Neumann factors of type  $II_1$  appearing in quantum TGD and allowing to formulate what might be called Feynman rules for cognition, and the hierarchy of dark matters would all reflect the same reflective hierarchy.

The experience with DNA suggests that nuclear strings could form coiled tight double helices for which only transversal degrees of freedom would appear as collective degrees of freedom. DNA allows a hierarchy of coilings and DNA molecules can also link and this could happen also now. Nuclei as collections of linked nuclear strings could perhaps be said to code the electromagnetic and color field bodies and it is difficult to avoid the idea that DNA would code in the same manner field bodies at which matter condenses to form much larger structures. The hierarchy of dark matters would give rise to a hierarchy of this kind of codings.

The linking and knotting of string like structures is the key element in the model of topological quantum computation and the large value of  $\hbar$  for dark matter makes it ideal for this purpose. I have already earlier proposed a model of DNA based topological quantum computation inspired by some strange numerical co-incidences [E9]. If dark matter is the essence of intelligent and intentional life at the level of molecular physics, it is difficult to see how it could not serve a similar role even at the level of elementary particle physics and provide kind of zoomed up "cognitive" representation for the ordinary matter.

The precise dark-visible correspondence might fail at the level of nuclei and nucleons because the lifetimes of the scaled down dark matter nucleons and nuclei are different from those of ordinary nucleons if dark matter is dark also with respect to weak interactions. The weak interaction rates in the lowest order are scaled up by the presence of  $1/m_W^4$  factors by a factor  $2^{-44}$  so that weak interactions are not so weak anymore. If dark electron and neutrino have their ordinary masses, dark proton and neutron would be stable. If also they appear as scaled down versions situation changes, but only a small change of the mass ratio of dark proton and neutron can make the weak decay of free dark neutron impossible kinematically and the one-to-one correspondence would make sense for stable nuclei. The beta decays of dark nuclei could however as a third order process with a considerable rate and change dramatically the weak decay rates of dark nuclei.

## 5 Neutron halos, tetra-neutron, and "sticky toffee" model of nucleus

Neutron halos and tetra neutron represent two poorly understood features of nuclear physics which all have been seen as suggesting the existence of an unknown long range force or forces.

### 5.1 Tetraneutron

There is evidence for the existence of tetra-neutrons [34]. Standard theory does not support their existence [35] so that the evidence for them came as a complete experimental surprise. Tetra-neutrons are believed to consist of 4 neutrons. In particular their lifetime, which is about 100 nanoseconds, is almost an eternity in the natural time scale of nuclear physics. The reason why the existing theory of nuclear force does not allow tetra-neutrons relates to Fermi statistics: the second pair of neutrons is necessarily in a highly energetic state so that a bound state is not possible.

Exotic quarks and charged color bonds provide perhaps the most natural explanation for tetra-neutron in TGD framework. In the model discussed hitherto only electromagnetically neutral color bonds have been considered but one can consider also charged color bonds in analogy allowing instead of neutral  $\pi$  and  $\rho$  also their charged companions. This would make possible to construct

from two protons and neutrons the analog of alpha particle by replacing two neutral color bonds with negatively charged bonds so that one would have two  $\bar{u}d$  p-n bonds and two  $\bar{u}u$  p-n bonds. Statistics difficulty would be circumvented and the state would decay to four neutrons via  $W$  boson exchange between quark of charged p-n bonds and protons. The model suggests the existence of also neutral variant of deuteron.

One can consider two options according to whether the exotic quarks have large  $\hbar$  but small  $c$  (Option II) or whether they are just p-adically scaled up quarks with  $k = 127$  (Option I). I have considered earlier a model analogous to option II but based on the hypothesis about existence of scaled down variant of QCD associated with Mersenne prime  $M_{127}$ . The so called leptohadron physics would also be associated with  $M_{127}$  and involve colored excitations of leptons [F7] which might also represent dark matter: in this case dark valence leptons with color would correspond to  $keff = 149$ , which happens to correspond to the thickness of the lipid layer of cell membrane.

The notion of many-sheeted space-time predicts the possibility of fractal scaled up/down versions of QCD which, by the loss of asymptotic freedom, exist only in certain length scale range and energy range. Thus the prediction does not lead to contradictions elementary particle physics limits for the number of colored elementary particles. The scaled up dark variants of QCD like theory allow to circumvent these problems even when asymptotic freedom is assumed.

In particular, pions and other mesons could exist for  $k = 127$  option as scaled down versions having much smaller masses. This lead to the earlier model of tetra-neutron as an ordinary alpha particle bound with two exotic pions with negative charges and having very small masses. This state looks like tetra-neutron and decays to neutrons weakly. The statistics problem is thus circumvented and the model makes precise quantitative predictions.

## 5.2 The formation of neutron halo and TGD

One counter argument against TGD inspired nuclear model is the short range of the nuclear forces: the introduction of the p-adic length scale  $L(113) \simeq 1.6E^{-14}$  m is in conflict with this classical wisdom. There exists however direct evidence for the proposed length scale besides the evidence from the p-n low energy scattering. Some light nuclei such as  ${}^8He$ ,  ${}^{11}Li$  and  ${}^{11}Be$  possess neutron halo with radius of size  $\sim 2.5E^{-14}$  m [20]. The width of the halo is rather large if the usual nuclear length scale is used as unit and the neutrons in the halo seem to behave as free particles. The short range of the nuclear forces makes it rather difficult to understand the formation of the neutron halo although the existing models can circumvent this difficulty. The proposed picture of the nucleus suggests a rather simple model for the halo.

For ordinary nuclei the densities of nucleons tend to be concentrated near the center of the nucleus. One can however consider the possibility of adding nucleons in vicinity of the boundary of the  $k = 111$  space-time sheet associated with the nucleus itself. The binding force would be color interaction between the color charges of color bonds and neutralizing color charge of colored gluons in the center (or in halo itself). Neutron halo would define a separate nucleus in the sense that states could be constructed by starting from the ground state. Halo would correspond to a quantum delocalized cluster of size of alpha particle.

The case  ${}^{11}Be$  provides support for the theory. Standard shell model suggests that six neutrons of  ${}^{11}Be$  fill completely  $1s_{\frac{1}{2}}$  and  $1p_{\frac{3}{2}}$  states while  $1p_{\frac{1}{2}}$  state holds one neutron so that  ${}^{11}Be$  ground state has  $J^\pi = \frac{1}{2}^-$  whereas experimentally ground state is known to have  $J^\pi = \frac{1}{2}^+$ . The system can be regarded as  ${}^{10}Be +$  halo neutron. The first guess is that the state could be simply of the following form

$$|0^+\rangle \times |2s_{1/2}\rangle . \quad (8)$$

Color force would stabilize this state. A more general state is a superposition of higher  $ns_{1/2}$  states

in order to achieve more sharp localization near boundary. This increases the kinetic energy of the neutron and the small binding energy of the halo neutron about  $2.5 \text{ MeV}$  implies that the kinetic energy should be of order  $5 - 6 \text{ MeV}$ . For instance, in the model described in [25] the halo neutron property and correct spin-parity for  $^{11}\text{Be}$  can be realized if the state is superposition of form

$$\begin{aligned} |^{11}\text{Be}\rangle &= a|0^+\rangle \times |2s_{1/2}\rangle + ba|2^+\rangle \times |21d_{5/2}\rangle , \\ a &\simeq .74 , \\ b &\simeq .63 . \end{aligned} \tag{9}$$

The correlation between the core and halo neutron is necessary in the model of [25] to produce bound  $1/2^+$  state. The halo neutron must also rotate.

The second example is provided by two-neutron halo nuclei, such as  $^{11}\text{Li}$  and  $^{12}\text{Be}$ , which do not bind single neutron but bind two neutrons. This looks mysterious since free neutrons do not allow bound states. A possible explanation is that the increase of the color Coulombic interaction energy of neutron color bonds with at least N-P dark gluons makes possible binding of neutron halo to the center nucleus. The situation would be analogous to the formation of planetary system. Order of magnitude estimate for color Coulombic interaction energy of halo neutron is  $E \sim (N - P)\alpha_s/L(113) \simeq (N - P) \times .8 \text{ MeV}$ . For  $N - P = 3$  the binding energy would be about  $2.3 \text{ MeV}$  and smaller than the experimental estimate  $2.5 \text{ MeV}$ . For  $N - P = 4$  this gives  $3.2 \text{ MeV}$  and larger than  $2.5 \text{ MeV}$  so that there is some room for the reduction of binding energy by the contribution from kinetic energy.

### 5.3 The "sticky toffee" model of Chris Illert for alpha decays

Chris Illert [36] has proposed what he calls "sticky toffee" model of alpha decay. The starting point of the work is a criticism of the wave-mechanical model for alpha decay of nuclei as occurring through tunnelling. The proposal is that tunnelling might allow a classical particle description after all. Quantum classical correspondence suggests the same in TGD framework.

The proposed description is based on the idea that the tunnelling alpha particle has abnormally small charge inside the tunnelling region. This reduces the electrostatic interaction of alpha particle with nucleus so that it can penetrate to otherwise classically non-allowed region separating it from the external world and can leak out of the parent nucleus. More quantitatively, the momentum given by  $p = \sqrt{2m(E - V)}$  of alpha particle remains real during tunnelling. As the alpha particle escapes, it gradually increases its charge to its full value of 2 units possessed by the ordinary alpha particle.

What is interesting is that the model predicts the charge of the proto-alpha particle at the surface of the decaying nucleus from the knowledge of alpha particle energy, nuclear radius, and charge by using just energy conservation in Coulombic field. What is assumed that the charge of the particle is such that Coulombic energy remains equal to the alpha particle energy all the way from the nuclear surface through the Coulomb wall to the distance where alpha particle can have full charge. This is a slight idealization since it would mean that the alpha particle kinetic energy vanishes.

To my opinion, the dynamical charge of alpha particle is a manner to articulate what happens in the tunnelling. Thus the model cannot replace quantum description but only become a part of it. In particular, the successful prediction of the decay rates exponentially sensitive to the alpha particle energy cannot be deduced from a purely classical theory.

The charges at the surface of the nucleus tend to be near  $1/3$  and  $2/3$ . What is amazing is that these charges correspond to the charges of the quark and anti-quark composing pion. That quarks should reveal themselves in the classical model for alpha decay is a complete surprise.

From this finding Illert concludes that during the decay the alpha particle is connected to the parent nucleus by rubber band like strings having quark and anti-quark at their ends, that is color flux tubes. These strings are interpreted as virtual pions. These strings get stretched and eventually must split since the color force between the quark and anti-quark at the ends of the string grows very strong.

This model is very attractive but has a deep problem: color forces mediate very short ranged and rapidly occurring interactions and should not be important for alpha decay which is a very slow process involving electromagnetic interactions in an essential manner. This does not diminish the pioneering value of Illert's work, just the opposite: pioneers must often have the courage to go against rationality as defined by the existing dogmas.

My earlier suggestion was that these pions serving as "rubber strings" are not ordinary pions but fractal copies of ordinary pions being much lighter and having much larger size. TGD indeed predicts the possibility of fractal copies of quantum chromo-dynamics (QCD). Thus there would exist a fractal copy of ordinary hadron physics operating in much longer length scales and having its own, much lighter, particle spectrum. The proposal was that this QCD corresponds to Mersenne prime  $M_{127}$ .

The dark QCD based on scaled up copies of ordinary quarks leads to a more elegant model in which virtual are replaced by  $\pi$  and  $\rho$  type color bonds, the latter being colored. Also an explanation of tetra-neutron emerges as a by-product since two pionic bonds can have negative charges. The identification of the nucleus as a nuclear string predicts the decay mechanism in which alpha particle pinches off and indeed has quarks and/or anti-quark attached to the ends of two nucleons.

Summarizing, although the model discussed in [36] does not predict tetra-neutron, it represents findings and ideas, which might be of crucial importance in the topological and geometric modelling of nuclear decays. The finding that alpha decay could be described in terms of pions, although wrong as such, opens the way to a realization that ordinary pions and thus also ordinary hadron and nuclear physics might have lighter fractal copies.

## 6 Tritium beta decay anomaly

The determination of neutrino mass from the beta decay of tritium leads to a tachyonic mass squared [37, 38]. I have considered several alternative explanations for this long standing anomaly.

1.  ${}^3\text{He}$  nucleus resulting in the decay could be fake (tritium nucleus with one positively charged color bond making it to look like  ${}^3\text{He}$ ). The idea that slightly smaller mass of the fake  ${}^3\text{He}$  might explain the anomaly: it however turned out that the model cannot explain the variation of the anomaly from experiment to experiment.
2. Much later I realized that also the initial  ${}^3\text{H}$  nucleus could be fake ( ${}^3\text{He}$  nucleus with one negatively charged color bond). It turned out that fake tritium option can explain all aspects of the anomaly and also other anomalies related to radioactive and alpha decays of nuclei.
3. The alternative based on the assumption of dark neutrino or antineutrino belt surrounding Earth's orbit and explain satisfactorily several aspects of the anomaly but fails in its simplest form to explain the dependence of the anomaly on experiment. Since the fake tritium scenario is based only on the basic assumptions of the nuclear string model [F9] and brings in only new values of kinematical parameters it is definitely favored.

### 6.1 Tritium beta decay anomaly

A brief summary of experimental data before going to the detailed models is in order.

### 6.1.1 Is neutrino tachyonic?

Nuclear beta decay allows in principle to determine the value of the neutrino mass since the energy distribution function for electrons is sensitive to neutrino mass at the boundary of the kinematically allowed region corresponding to the situation in which final neutrino energy goes to zero [27].

The most useful quantity for measuring the neutrino mass is the so called Kurie plot for the function

$$\begin{aligned} K(E) &\equiv \left[ \frac{d\Gamma/dE}{pEF(Z, E)} \right]^{1/2} \sim (E_\nu k_\nu)^{1/2} = \left[ E_\nu \sqrt{E_\nu^2 - m(\nu)^2} \right]^{1/2} , \\ E_\nu &= E_0 - E \quad , \quad E_0 = M_i - M_f - m(\nu) . \end{aligned} \quad (10)$$

Here  $E$  denotes electron energy and  $E_0$  is its upper bound from energy and momentum conservation (for a configuration in which final state nucleon is at rest). Mass shell condition lowers the upper bound to  $E \leq E_0 - m(\nu)$ . For  $m(\nu) = 0$  Kurie plot is straight line near its endpoint. For  $m(\nu) > 0$  the end point is shifted to  $E_0 - m(\nu)$  and  $K(E)$  behaves as  $m(\nu)^{1/2} k_\nu^{1/2}$  near the end point.

The problem is that the determination of  $m(\nu)$  from this parametrization in tritium beta decay experiments gives a negative mass squared varies and is  $m(\nu)^2 = -147 \pm 68 \pm 41 \text{ eV}^2$  according to [27]! This behavior means that the derivative of  $K(E)$  is infinite at the end point  $E_0$  and  $K(E)$  increases much faster near end point than it should. One can quite safely argue that tachyonicity gives only an ad hoc parametrization for the change of the shape of the function  $K$  deriving from some unidentified physical effect: in particular, the value of the tachyonic mass must correspond to a parameter related to new physics and need not have anything to do with neutrino mass.

### 6.1.2 More detailed experimental data

The results of Troitsk and Mainz experiments can be taken as constraints of the model. In Troitsk experiments [37] gas phase tritium is used whereas in Mainz experiments [38] liquid tritium film is used.

Troitsk experiments are described in [37]. In 1944 Troitsk experiment, the enhancement of the spectrum intensity was found to begin roughly at  $V_b \simeq 7.6 \text{ eV}$  below  $E_0$ . The conclusion was that the rise of the spectrum intensity below 18,300 eV with respect to the standard model prediction takes place (this is illustrated in fig. 4 of [37]). No bump was claimed in this paper. In the analysis of 1996 experiment Troitsk group however concluded that the trapping of electrons gives rise to the enrichment of the low energy spectrum intensity of electrons and that when takes this effect into account, a narrow bump results.

Figure 4 of [37] demonstrates that spectrum intensity is below the theoretical value near the endpoint (right from the bump). In [37] the reduction of the spectrum intensity was assumed to be due to non-vanishing neutrino mass in [37]. The determination of  $m(\nu)$  from the data near the end point assuming that beta decay is in question [37] gives  $m(\nu) \sim 5 \text{ eV}$ .

The data can be parameterized by a parameter  $V_b$  which in the model context can be interpreted as repulsive interaction energy of antineutrinos with condensed matter suggested to explain the bump. Accordingly, the parametrization of  $K(E)$  near the end point is

$$K(E) \sim (E - E_0)\theta(E - E_0) \rightarrow (E - E_0)\theta(E - E_0 + V_b) .$$

The end point is shifted to energy  $E_\nu = V_b$  and  $K(E)$  drops from the value  $V_b$  to zero at at this energy.

The values of  $V_b$  deduced from Troitsk and Mainz experiments are in the range 5 – 100 eV. The value of  $V_b$  observed in Troitsk experiments using gas phase tritium [37] was of order 10 eV.

In Mainz experiment [38] tritium film was used and the excess of counts around energy  $V_b \simeq 100$  eV below  $E_0$  was observed.

There is also a time variation involved with the value of  $V_b$ . In 1944 experiment [37] the bump was roughly  $V_b \simeq 7.6$  eV below  $E_0$ . In 1996 experiment [37] the value of  $V_b$  was found to be  $V_b \simeq 12.3$  eV [38]. Time variation was observed also in the Mainz experiment. In 'Neutrino 98' conference an oscillatory time variation for the position of the peak with a period of 1/2 years in the amplitude was reported by Troitsk group.

## 6.2 Could TGD based exotic nuclear physics explain the anomaly?

Nuclear string model explains tetra-neutron as alpha particle with two negatively charged color bonds. This inspires the question whether some fraction of decays could correspond to the decays of tritium to fake  ${}^3\text{He}$  (tritium with one positively charged color bond) or fake tritium ( ${}^3\text{He}$  with one negatively charged color bond) to  ${}^3\text{He}$ .

### 6.2.1 Could the decays of tritium decay to fake ${}^3\text{He}$ explain the anomaly?

Consider first the fake  ${}^3\text{He}$  option. Tritium (pnn) would decay with some rate to a fake  ${}^3\text{He}$ , call it  ${}^3\text{He}_f$ , which is actually tritium nucleus containing one positively charged color bond and possessing mass slightly different than that of  ${}^3\text{He}$  (ppn).

1. In this kind of situation the expression for the function  $K(E, k)$  differs from  $K(\text{stand})$  since the upper bound  $E_0$  for the maximal electron energy is modified:

$$\begin{aligned} E_0 &\rightarrow E_1 = M({}^3\text{H}) - M({}^3\text{He}_f) - m_\mu = M({}^3\text{H}) - M({}^3\text{He}) + \Delta M - m_\mu , \\ \Delta M &= M({}^3\text{He}) - M({}^3\text{He}_f) . \end{aligned} \quad (11)$$

Depending on whether  ${}^3\text{He}_f$  is heavier/lighter than  ${}^3\text{He}$   $E_0$  decreases/increases. From  $V_b \in [5 - 100]$  eV and from the TGD based prediction order  $m(\bar{\nu}) \sim .27$  eV one can conclude that  $\Delta M$  should be in the range 10-200 eV.

2. In the lowest approximation  $K(E)$  can be written as

$$K(E) = K_0(E, E_1, k)\theta(E_1 - E) \simeq (E_1 - E)\theta(E_1 - E) . \quad (12)$$

Here  $\theta(x)$  denotes step function and  $K_0(E, E_0, k)$  corresponds to the massless antineutrino.

3. If a fraction  $p$  of the final state nuclei correspond to a fake  ${}^3\text{He}$  the function  $K(E)$  deduced from data is a linear combination of functions  $K(E, {}^3\text{He})$  and  $K(E, {}^3\text{He}_f)$  and given by

$$\begin{aligned} K(E) &= (1 - p)K(E, {}^3\text{He}) + pK(E, {}^3\text{He}_f) \\ &\simeq (1 - p)(E_0 - E)\theta(E_0 - E) + p(E_1 - E)\theta(E_1 - E) \end{aligned} \quad (13)$$

in the approximation  $m_\nu = 0$ .

For  $m({}^3\text{He}_f) < m({}^3\text{He})$  one has  $E_1 > E_0$  giving

$$K(E) = (E_0 - E)\theta(E_0 - E) + p(E_1 - E_0)\theta(E_1 - E)\theta(E - E_0) . \quad (14)$$

$K(E, E_0)$  is shifted upwards by a constant term  $p\Delta M$  in the region  $E_0 > E$ . At  $E = E_0$  the derivative of  $K(E)$  is infinite which corresponds to the divergence of the derivative of square root function in the simpler parametrization using tachyonic mass. The prediction of the model is the presence of a tail corresponding to the region  $E_0 < E < E_1$ .

4. The model does not as such explain the bump near the end point of the spectrum. The decay  ${}^3\text{H} \rightarrow {}^3\text{He}_f$  can be interpreted in terms of an exotic weak decay  $d \rightarrow u + W^-$  of the exotic  $d$  quark at the end of color bond connecting nucleons inside  ${}^3\text{H}$ . The rate for these interactions cannot differ too much from that for ordinary weak interactions and  $W$  boson must transform to its ordinary variant before the decay  $W \rightarrow e + \bar{\nu}$ . Either the weak decay at quark level or the phase transition could take place with a considerable rate only for low enough virtual  $W$  boson energies, say for energies for which the Compton length of massless  $W$  boson correspond to the size scale of color flux tubes predicted to be much longer than nuclear size. Is so the anomaly would be absent for higher energies and a bump would result.
5. The value of  $K(E)$  at  $E = E_0$  is  $V_b \equiv p(E_1 - E_0)$ . The variation of the fraction  $p$  could explain the observed dependence of  $V_b$  on experiment as well as its time variation. It is however difficult to understand how  $p$  could vary.

### 6.2.2 Could the decays of fake tritium to ${}^3\text{He}$ explain the anomaly?

Second option is that fraction  $p$  of the tritium nuclei are fake and correspond to  ${}^3\text{He}$  nuclei with one negatively charged color bond.

1. By repeating the previous calculation exactly the same expression for  $K(E)$  in the approximation  $m_\nu = 0$  but with the replacement

$$\Delta M = M({}^3\text{He}) - M({}^3\text{He}_f) \rightarrow M({}^3\text{H}_f) - M({}^3\text{H}) . \quad (15)$$

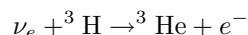
2. In this case it is possible to understand the variations in the shape of  $K(E)$  if the fraction of  ${}^3\text{H}_f$  varies in time and from experiment to experiment. A possible mechanism inducing this variation is a transition inducing the transformation  ${}^3\text{H}_f \rightarrow {}^3\text{H}$  by an exotic weak decay  $d + p \rightarrow u + n$ , where  $u$  and  $d$  correspond to the quarks at the ends of color flux tubes. This kind of transition could be induced by the absorption of X-rays, say artificial X-rays or X-rays from Sun. The inverse of this process in Sun could generate X rays which induce this process in resonant manner at the surface of Earth.
3. The well-known poorly understood X-ray bursts from Sun during solar flares in the wavelength range 1-8 Å [44] corresponds to energies in the range 1.6-12.4 keV, 3 octaves in good approximation. This radiation could be partly due to transitions between ordinary and exotic states of nuclei rather than brehmstrahlung resulting in the acceleration of charged particles to relativistic energies. The energy range suggests the presence of three p-adic length scales: nuclear string model indeed predicts several p-adic length scales for color bonds corresponding to different mass scales for quarks at the ends of the bonds [F9]. This energy range is considerably above the energy range 5 – 100 eV and suggests the range  $[4 \times 10^{-4}, 6 \times 10^{-2}]$  for the values of  $p$ . The existence of these excitations would mean a new branch of low energy nuclear physics, which might be dubbed X-ray nuclear physics. The energy scale of for the excitation energies of exotic nuclei could corresponds to Coulomb interaction energy  $\alpha_{em}m$ , where  $m$  is mass scale of the exotic quark. This means energy scale of 10 keV for MeV mass scale.

4. The approximately 1/2 year period of the temporal variation would naturally correspond to the  $1/R^2$  dependence of the intensity of X-ray radiation from Sun. There is evidence that the period is few hours longer than 1/2 years which supports the view that the origin of periodicity is not purely geometric but relates to the dynamics of X-ray radiation from Sun. Note that for 2 hours one would have  $\Delta T/T \simeq 2^{-11}$ , which defines a fundamental constant in TGD Universe and is also near to the electron proton mass ratio.
5. All nuclei could appear as similar anomalous variants. Since both weak and strong decay rates are sensitive to the binding energy, it is possible to test this prediction by finding whether nuclear decay rates show anomalous time variation.
6. The model could explain also other anomalies of radioactive reaction rates including the findings of Shnoll [41] and the unexplained fluctuations in the decay rates of  $^{32}\text{Si}$  and  $^{226}\text{Ra}$  reported quite recently [42] and correlating with  $1/R^2$ ,  $R$  distance between Earth and Sun.  $^{226}\text{Ra}$  decays by alpha emission but the sensitive dependence of alpha decay rate on binding energy means that the temporal variation of the fraction of fake  $^{226}\text{Ra}$  isotopes could explain the variation of the decay rates. The intensity of the X-ray radiation from Sun is proportional to  $1/R^2$  so that the correlation of the fluctuation with distance would emerge naturally.
7. Also a dip in the decay rates of  $^{54}\text{Mn}$  coincident with a peak in proton and X-ray fluxes during solar flare [43] has been observed: the proposal is that neutrino flux from Sun is also enhanced during the solar flare and induces the effect. A peak in X-ray flux is a more natural explanation in TGD framework.
8. The model predicts interaction between atomic physics and nuclear physics, which might be of relevance in biology. For instance, the transitions between exotic and ordinary variants of nuclei could yield X-rays inducing atomic transitions or ionization. The wave length range 1-8 Angstroms for anomalous X-rays corresponds to the range  $Z \in [11, 30]$  for ionization energies. The biologically important ions  $\text{Na}^+$ ,  $\text{Mg}^{++}$ ,  $\text{P}^-$ ,  $\text{Cl}^-$ ,  $\text{K}^+$ ,  $\text{Ca}^{++}$  have  $Z = (11, 15, 17, 19, 20)$ . I have proposed that  $\text{Na}^+$ ,  $\text{Cl}^-$ ,  $\text{K}^+$  (fermions) are actually bosonic exotic ions forming Bose-Einstein condensates at magnetic flux tubes [M2]. The exchange of  $W$  bosons between neutral Ne and A(rgon) atoms (bosons) could yield exotic bosonic variants of  $\text{Na}^+$  (perhaps even  $\text{Mg}^{++}$ , which is boson also as ordinary ion) and  $\text{Cl}^-$  ions. Similar exchange between A atoms could yield exotic bosonic variants of  $\text{Cl}^-$  and  $\text{K}^+$  (and even  $\text{Ca}^{++}$ , which is also boson as ordinary variant). This hypothesis is testable by measuring the nuclear weights of these ions. X-rays from Sun are not present during night time and this could relate to the night-day cycle of living organisms. Note that magnetic bodies are of size scale of Earth and even larger so that the exotic ions inside them could be subject to intense X-ray radiation. X-rays could also be dark X-rays with large Planck constant and thus with much lower frequency than ordinary X-rays so that control could be possible.

### 6.3 The model based on dark neutrinos

A common origin of the tritium beta decay anomaly was independently suggested by several groups (see [39]): a broad spike or bump like excess of counts centered 5 – 100 eV below the end point energy  $E_0$ . In [39] it was suggested that a repulsive interaction of antineutrinos with condensed matter with interaction energy of order  $V_b \simeq 5 - 100$  eV could explain the bump.

It has been pointed out by Stevenson [40] that the process in which neutrinos are absorbed from a background of electron neutrinos





leads to electrons in the anomalous endpoint region. This gives an essentially constant addition to the region  $E_0 - E_F < E < E_0$ . The density of cosmic neutrino background is however far too small to give the required large background density of order  $1/m(\nu)^3$ .

The earlier -wrong- hypothesis that nuclei are  $Z^0$  charged are consistent with both options described above as explanations of the anomaly. One can modify these models to apply also in the new framework. The problem of these models is that one is forced to make ad hoc assumptions about dynamics in long length scales. They might make sense in TGD Universe but would require experimental justification. These models in their simplest form fail also to explain the dependence of  $V_b$  on experiment and fail to provide provide insights about more general time variations of nuclear decay rates.

### 6.3.1 Neutrino belt or antineutrino belt?

The model corresponding to mechanism of [39] is that the belt consists of dark antineutrinos and the repulsive interaction energy of antineutrino with the these neutrinos explains the anomaly. The model based on dark neutrinos assumes that Earth's orbit is surrounded by a belt of dark neutrinos and that the mechanism proposed in [40] could be at work. The periodic variation of the dark neutrino density along the orbit of Earth around Sun could also explain the periodic variations of the bump.

1. The first mechanism corresponds to that suggested in [39]. The antineutrino emitted in the beta decay can transform to a dark neutrino by mixing and experiences a repulsive  $Z^0$  force which effectively shifts the electron energy spectrum downwards. In this case the repulsive interaction energy  $V_b$  of dark anti-neutrinos with the dark antineutrinos of the solar belt would replace  $\Delta M$  in the previous formula:

$$E_0 = M(^3\text{H}) - M(^3\text{He}) - m(\nu) \rightarrow M(^3\text{H}) - M(^3\text{He}) - V_b - m(\nu_d) . \quad (16)$$

2. Second option corresponds to the mechanism proposed in [40]. Dark neutrino transforms to ordinary one and induces by ordinary  $W$  exchange ordinary tritium beta decay. In this case the Fermi energy  $E_F$  of dark neutrino determines the width of the bump and one has  $V_b = E_F$ :

$$E_0 = M(^3\text{H}) - M(^3\text{He}) - m(\nu) \rightarrow M(^3\text{H}) - M(^3\text{He}) - E_F + m(\nu_d) . \quad (17)$$

The rate of the process would be given by the standard model and only the density of dark neutrinos and the ratio  $M^2(\nu, \nu(\text{dark}))/M^2(\nu)$  appear as free parameters.

Notice that these models are simpler than the original models which assumed that the interaction of neutrinos with condensed matter carrying  $Z^0$  charge is involved. The explanation for the dependence of  $V_b$  on experiment poses a difficulty for both models. For the antineutrino belt the repulsive interaction energy is proportional to the density of antineutrinos. For neutrino belt  $V_b$  corresponds to the Fermi energy proportional to the density of neutrinos. In both cases large variation of  $V_b$  requires a large variation of the density of antineutrinos (neutrinos) of the belt in the scale smaller than Earth size. This does not look too plausible.

### 6.3.2 Can one understand time variation of $V_b$ ?

The periodic variation of the density of neutrinos or antineutrinos in the belt should induce the variation of  $V_b$ . The ordering of the two models trying to explain this variation reflects the evolution of the general ideas about quantum TGD.

#### 1. First model

The value of the period and the fact that maximum shift occurs when Earth is near to its position nearest to Sun suggests that the physics of solar system must be involved somehow. The simplest explanation is that gravitational acceleration tends to drive dark neutrinos (antineutrinos) as near as possible to Sun inside the belt. In thermal equilibrium with temperature  $T$  the Boltzmann factor

$$\exp\left(-\frac{V_{gr}}{T}\right) = \exp\left(-\frac{GMm(\nu_d)}{rT}\right) \quad (18)$$

for the dark neutrino would determine the density profile of dark neutrinos along the belt as function of the distance  $r$  to the Sun.

The existence of the dark neutrino belt conforms with the model of for the formation of solar system from dark matter with a gigantic value of Planck constant discussed in [D6, J6]. The model indeed assumes that the dark matter is located at space-time sheet surrounding the orbit of Earth. The requirement that dark neutrino density is few neutrinos per atomic volume in the belt leads to a lower bound for the mass of the belt:

$$M(\text{belt}) \simeq m(\nu_d) \frac{\text{Vol}(\text{belt})}{a^3} > 10^{-11} M(\text{Sun}) \quad (a \simeq 10^{-10} \text{ meters}) . \quad (19)$$

Here it is assumed that the dark neutrino mass is same as neutrino mass, which of course is an un-necessarily strong assumption. If the belt is at rest, the time period for the variation of the tritium beta decay anomaly is exactly half year. The period seems to be few hours longer than one half year (as reported in Neutrino98 conference in Tokyo by Lobashev *et al*) [37], which suggests that belt rotates slowly relative to Earth in the same direction as Earth.

#### 2. Second model

The model for radioactive decay rate anomalies requires that neutrinos and Earth move respect to each other and that the density of neutrinos in the laboratory volume varies along the orbit.

1. Assume first that ordinary quantum mechanics applies and neutrinos are ordinary. The simplest expectation from Equivalence Principle assuming that neutrinos and Earth move independently along geodesic lines is that the velocity is same for Earth and neutrinos. No effect results even if the density of neutrinos along the orbit varies.
2. Suppose that the neutrinos are dark in the sense of having gigantic gravitational Planck constant and are in a macroscopically quantum coherent phase delocalized along the entire orbit and described by a wave function (also neutrino Cooper pairs can be considered). If the neutrino ring is exactly circular as Bohr orbit picture suggests and contains Earth's orbit, the thickness of the ring must be at least  $d = a - b$ , where  $a$  and  $b$  are major and minor axis. Exact rotational symmetry implies that dark neutrinos are characterized by a phase factor characterizing the angular momentum eigen state in question (the unit of the quantized angular momentum is now very large). Thus neutrino density depends only on the transversal coordinates of the tube and vanishes at the boundary of the tube. Since the Earth's orbit is ellipse, the transversal variation of the neutrino density inside the tube

induces periodic variations of the neutrino density in the detector and could explain the effects on radioactive decay rates.

Although the model might explain the time variation of  $V_b$  it does not provide any obvious explanation for beta decay rates in general and fails to explain the variation of the alpha decay rate of  $^{226}\text{Ra}$  nor the correlation of decay rates with solar flares. Hence it is clear that the model involving only the notion of nuclear string is favored.

## 6.4 Some other apparent anomalies made possible by dark neutrinos

The appearance of dark neutrinos in the final states of beta decays allow to imagine also some other apparent anomalies.

### 6.4.1 Apparent anomaly in the inverse beta decay

For the antineutrino belt option one can consider also the possibility of an apparent anomaly in the inverse beta decay in which positron and neutrino are emitted but only electron observed. The apparent anomaly would result from the absorption of a dark antineutrino with repulsive  $Z^0$  interaction energy with condensed matter.

In this case the value of  $E_0$  increases

$$E_0 = M_i - M_f - m(\nu) \rightarrow \hat{E}_0 = M_i - M_f + m(\nu_d) + V_b , \quad (20)$$

which means that positron spectrum extends above the kinematic limit if  $V_b$  has the value predicted by the explanation of tritium beta decay anomaly.

A second anomalous situation results if the emitted neutrino transforms to a dark neutrino with negative binding energy. In this case the value of  $E_0$  would change as

$$E_0 \rightarrow \hat{E}_0 = M_i - M_f - m(\nu_d) + V_b . \quad (21)$$

### 6.4.2 Apparently neutrinoless beta decay and double beta decay

Neutrinoless double beta decay (NDB) is certainly one of the most significant nuclear physics processes from the point of view of unified theories (the popular article of New Scientist [45] provides a good view of NDB and the recent rather exciting experimental situation). In the standard physics framework NDB can occur only if neutrinos are Majorana neutrinos so that neutrino number is conserved only modulo 2 meaning that neutrino and antineutrino are one and the same particle. Since no antineutrinos are emitted in the NDB, the total energy of the two electrons is larger than in the normal double beta decay, and serves as an experimental signature of the process.

There are several collaborations studying NDB. The team formed by Hans Klapdor-Kleingrothaus and colleagues from the the Max Planck Insitute for Nuclear Physics in Heidelberg have been studying this process since 1990 in Gran Sasso laboratory. The decays studied are decays of Germanium-76 isotope known to be one of the few isotopes undergoing ordinary double beta decay transforming it into Selenium. The energy of the emitted two electrons is absorbed by the surrounding Ge atoms. The total energy which is larger for NDB decay serves as a signature of the process.

Three years ago came the first paper of the Heidelberg group reporting the observation of 15 NDB decays [46]. The analysis of the experiments however received a very critical response from colleagues. The Kurchatov Institute quitted the collaboration at 2001 and represented its own

analysis with the conclusion that the data do not support NDB. Three years later Heidelberg group represented 14 new candidates for NDB and a new analysis [47]. It is now admitted that the team is not obviously wrong but that there are still doubts whether the background radioactivity has been handled correctly.

In TGD Universe neutrinos are Dirac neutrinos and NDB is not possible. The possibility of dark neutrinos however allow to consider the possibility of apparently neutrinoless beta decay and double beta decay.

What would happen that the ordinary neutrino emitted in the beta decay of proton transforms into a dark neutrino by mixing. The dark neutrino would not be observed so that apparently neutrinoless beta decay would be in question. Dark neutrino has a negative interaction energy with condensed matter assuming that the explanation of tritium beta decay anomaly is correct so that electron would have an anomalously high energy. The process cannot occur if the negative energy states of the Fermi sea are filled as indeed suggested by energetic considerations.

The generalization of this process would be double beta decay involving strong interaction between decaying neutrons mediated by color bond between them and the transformation of second neutrino to dark neutrino with negative energy so that the electrons would have anomalously high energy. The same objection applies to this process as to the apparently neutrinoless beta decay.

## 7 Cold fusion and Trojan horse mechanism

The model for cold fusion has developed gradually as the understanding of quantum TGD and many-sheeted space-time has developed. Trojan horse mechanism has served as the connecting thread between various models. The last step of progress relates to the new vision about nuclear physics but it is still impossible to fix the model completely unless one poses the condition of minimality and the requirement that single mechanism is behind various anomalies.

### 7.1 Exotic quarks and charged color bonds as a common denominator of anomalous phenomena

There should exist a common denominator for anomalous behavior of water, cold fusion, the findings of Ditmire suggesting cold fusion, sono-fusion, exotic chemistries, strange properties of living matter including chiral selection, and also phenomena like low compressibility of condensed matter which standard physicist would not be worried about.

It seems that compression inducing the generation of charged color bonds between nucleons and leading to a formation of super-nuclei with atomic distances between building blocks might be the sought for common denominator. For super nuclei the repulsive weak interactions between exotic quark and anti-quark belonging to the two bonded nuclei would compensate the attractive color force so that a stable configuration of atomic size would result. Note that the weak coupling strength would be actually strong by the general criterion for transition to the large  $\hbar$  phase.

The charging of color bonds would occur via  $W$  boson exchange between exotic and valence quarks with exotic  $W$  boson transforming to ordinary  $W$  via mixing.

The alternative option is a phase transition of nuclei transforming  $k = 113$  em space-time sheets of valence quarks to em dark space-time sheets with a large value of  $\hbar$  suggested for heavier nuclei by the general criteria. This phase transition could be avoided if the criticality forces surplus protons to transfer the electromagnetic charge of valence quarks to color bonds so that the situation reduces to the first option. In this picture standard nuclear physics would remain almost untouched and nothing new expect exotic quarks and charged color bonds is introduced.

The following examples suggest that this general picture indeed might unify a large class of phenomena.

1. The super-nuclei formed by the dark protons of water would be a basic example about this phenomenon. The occurrence of the process is plausible if also nucleons possess or can generate closed loops with exotic quark and anti-quark at the ends of the loop belonging to the same nucleon. The fact that these protons are dark with respect to electromagnetic interactions suggests that the charge of protons is transferred to the color bonds so that the outcome is a nuclear string formed from neutrons connected by positively charged color bonds. Darkness with respect to weak interactions suggests that valence quarks are doubly dark. This would mean that the p-adic length scale of color bonds would correspond to  $k_{eff} = 107 + 2 \times 22 = 151$  for  $\hbar_s = n^2 \hbar / v_0^2$ ,  $n = 1$ . This corresponds to the thickness of cell membrane so that the structure of water would contain information about the basic biological length scale.

2. In condensed matter the super-nuclei would form at some critical pressure when weakly charged color bonds between neighboring nuclei become possible and compensate the attractive color force. This would explain the low compressibility of condensed matter.

3. Bio-polymers in vivo might correspond to super-nuclei connected by charged color bonds whose weak charges would explain the large parity breaking involve with chiral selection. Hydrogen bond might be a basic example of a charged color bond. It could be that the value of integer  $n$  in  $\hbar_s = n\hbar/v_0$  is  $n = 3$  in living matter and  $n = 1$  in ordinary condensed matter.

Trojan horse mechanism might work also at the level of chemistry making possible to circumvent electronic Coulomb wall and might be an essential characteristic of the catalytic action. Note that Pd is also a powerful catalyst.  $n = 1$  might however distinguish it from bio-catalysts. In separate context I have dubbed this mechanism as 'Houdini effect'.

The reported occurrence of nuclear transmutations [63, 64] such as  $^{23}\text{Na} + ^{16}\text{O} \rightarrow ^{39}\text{K}$  in living matter allowing growing cells to regenerate elements K, Mg, Ca, or Fe, could be understood as fusion of neighboring nuclei connected by charged color bond which becomes neutral by  $W$  emission so that collapse to single nucleus results in absence of the repulsive weak force. Perhaps it is someday possible to produce metabolic energy by bio-fusion or perhaps Nature has already discovered the trick!

4. In cold fusion the nuclei of target D and Pd would combine to form super-nuclei connected by charged color bonds. This would explain why the heavy loading of Pd nuclei with D (for a review of loading process see [57]) does not generate enormous pressures. Cold fusion would occur in some critical interval of loadings allowing ordinary and exotic nuclei to transform to each other. The transfer of the em charge of D to the color bond connecting D and Pd would make D effectively nn state. Together with the fact that the color bond would have length of order atomic radius would mean that the Coulomb wall of Pd and D is not felt by beam nuclei and Trojan horse mechanism would become possible. The prediction is that Coulomb wall disappears only only when deuterium or tritium target is used. If nuclei can transform to dark em phase cold fusion could occur for arbitrary target nuclei. That it is observed only for D and possibly H does not support this option.

If valence quarks are doubly dark, their magnetic bodies have size of order  $L(151) = 10$  nm, which is also the size scale of the nano-scaled Pd particles, color force would become long ranged. In sono-luminescence and son-fusion and also in nuclear transmutations similar formation of super-nuclei would occur and the collapse of super-nucleus to single nucleus could occur by the proposed mechanism.

5. In the experiments of Ditmire *et al* laser pulse induces very dense phase of Xenon atoms having  $Z = 54$  which is heated to energies in which electron energies extend to MeV region and expands rapidly.  $Z = 54$  means that Xe satisfies the most stringent condition of criticality

for the transition to electromagnetic large  $\hbar$  phase. This transition does not occur if protons feed the surplus em charge to the color bonds so that Xe nuclei also weakly charged. Assume that some fraction of Xe is in this kind of phase. The compression of Xe gas by laser pulse compresses Xe super-nuclei. If the connecting charged color bonds emit their em and weak charge by emission of W boson the super-nuclei collapse to single nucleus and nuclear fusion reactions become possible. The repulsive weak force becoming manifest in the compression generates brehmstrahlung heating the system and induces a violent explosion much like in sono-fusion.

In the sequel the experiments Ditmire *et al* and cold fusion are discussed in detail using this model.

## 7.2 The experiments of Ditmire *et al*

An important stimulation in the development of the model for cold fusion came from the observations of Ditmire *et al* [48] published in Nature. The discovery was that the energy spectrum of electrons in ionic explosions induced by the laser heating of ionic clusters extends up to energies of order MeV (rather  $10^2$  eV(!)): this suggests strongly a mechanism making strong interactions possible.

In the experimental arrangement of Ditmire *et al* clusters of Xenon atoms are hit by ultrashort (150 fsec), high-intensity ( $2 \times 10^{16}$  W/cm<sup>2</sup>) laser pulses[48]. This leads to superheating and production of high energy ions in the explosions of the superheated clusters. The highest ion energies are by 4 orders of magnitude larger than expected and of order MeV, the typical energy scale of nuclear strong interaction. The average ion energy is  $45 \pm 5$  keV for cluster size of 6.5 nm and decreases slowly with the size of the cluster. No hot ions are produced for small clusters containing less than  $\sim 100$  Xe atoms. It is not yet understood why the clusters explode so much more violently than molecules (producing 1 MeV ions as opposed to 100 eV ions) and small clusters. Another striking feature of the laser-cluster interaction is ionization to very high charge states, much higher than in the ionization, which can be produced by simple field ionization.

Consider first a more detailed model of the superheating as it is described in [48].

*In an intensely irradiated cluster, optically and collisionally ionized electrons undergo rapid collisional heating for the short time ( $< ps$ ) before the cluster disassembles in the laser field. Our recent studies of the electron energy spectra produced by the high intensity irradiation of large Xe clusters with 150 fs laser pulse indicate that collisional heating within the cluster can produce electrons with energy up to 3 keV, an energy much higher than that typical of solid target plasmas.*

*A sharp peak in the measured electron energy spectrum suggested that the cluster micro-plasma exhibited a resonance in the heating by laser pulse similar to the giant resonance seen in metallic clusters. A small amount of cluster expansion during the laser pulse lowers the electron density to bring the near-infrared laser light into resonance with the free-electron plasma frequency in the cluster. This resonance greatly increases the laser electric field density within the cluster, and the laser absorption rate is enhanced, rapidly heating the electrons on a very fast ( $< 10$  fs) time scale to a highly non-equilibrium superheated state with mean energies of many keV. Charge separation of hot electrons inevitably leads to a very fast expansion of the cluster ions. This process is fundamentally different from low-intensity photo-fragmentation of cluster and far more energetic than the Coulomb explosion of small molecules.*

Authors believe (rather naturally!) that the production of hot ions is made possible by the high ion-temperatures produced by the not yet properly understood heating mechanism and suggest that this mechanism might make even table-top fusion possible.

In TGD framework the proposed general vision suggests following picture.

1. Laser pulse induces a compression of clusters of Xe atoms already containing super-nuclei with charged color bonds so that repulsive weak interaction compensated by color force in

equilibrium situation becomes manifest and induces the expansion of the system much like the expansion of the bubble in sono-luminescence. The resulting brehmstrahlung heats the system.

2. The critical cluster size 6.5 nm could correspond to the p-adic length length scale  $L(k_{eff} = 151) = 10$  nm for doubly dark valence quarks with  $n = 1$ .
3. The nuclear fusions resulting when color bonds between nuclei become neutral and induce collapse to single nucleus. Anomalously high charge states could be a byproduct of violent and very rapid fusions of neighboring color bonded Xe nuclei tearing Xe nuclei and outer electrons apart. These fusions would generate quantum coherent dark gamma ray beams transforming to ordinary gamma rays by de-coherence transition reducing the wavelength of gamma rays by a factor of  $2^{-11}$  for  $\hbar_s = \hbar/v_0$ . It is also possible that dark gamma rays are absorbed by Pd super-nuclei. The wavelengths of dark gamma rays with energy of MeV would of order 2 nanometers in this case so that a coherent heating would happen in rather large volume.

### 7.3 Brief summary of cold fusion

In the following history and signatures of cold fusion are briefly summarized.

#### 7.3.1 History of cold fusion

The first claim for cold fusion [58] dates back to March 23, 1989, when Pons and Fleischmann announced that nuclear fusion, producing usable amounts of heat, could be induced to take place on a table-top by electrolyzing heavy water and using electrodes made of Pd and platinum. Various laboratories all-over the world tried to reproduce the experiments. The poor reproducibility and the absence of the typical side products of nuclear fusion (gamma rays and neutrons) led soon to the conclusion (represented in the dramatic session of American Physical Society May 1, 1989) that nuclear fusion cannot explain the heat production. Main stream scientists made final conclusions about the subject of 'cold fusion' and cold fusion people became a pariah class of the scientific community.

The work with cold fusion however continued and gradually situation has changed. It became clear that nuclear reaction products, mainly  ${}^4\text{He}$ , are present. Gradually also the reasons for the poor reproducibility of the experiments became better understood. A representative example about the change of the attitudes is the article of Schwinger [49] in which cold fusion is taken seriously. The article also demonstrates that the counter arguments of hot fusion people are based on the implicit assumption that hot fusion theory describes cold fusion despite the fact that the physical situations are radically different.

The development on the experimental side has been based on techniques involving the use of catalysis, nanotechnology, electrolysis, glow discharge and ultrasonic cavitation. There are now public demonstrations of cold fusion reactors, whose output energy far exceeds input energy and commercial applications are under intensive development, see for instance the home page of Russ George [59], for whom I am grateful for informing me about the recent state of cold fusion.

Rather remarkably, also the production of heavier elements has been detected [60] and this makes the explanation of the effect even more difficult in standard physics context and definitely excludes the explanations claiming that some chemical process is the source of the excess heat. The possibility of nuclear transmutation also suggests the possibility to transform ordinary nuclear wastes into non-radioactive nuclei and the first method achieving this has already been reported [61]. There are claims [63, 64] that cold fusion indeed occurs in bio-systems.

There is also some evidence for high temperature super conductivity associated with deuterium loaded palladium [60]. Good representations about the subject of cold fusion and references to the

experimental work can be found at various cold fusion web-sites [62, 52, 53, 59]. Also the articles of J. Rothwell [60] and the excellent review article of E. Storms [55] are recommended.

It has become clear that cold fusion differs from hot fusion in several respects: gamma rays are not produced and the flux of neutrons is much lower than predicted by standard nuclear physics (these features are very well-come from the point of view of the technological applications). Together with the fact that Coulomb wall does not allow the occurrence of cold fusion at all in the standard physics context, this forces the conclusion that new physics must be involved.

It seems that TGD indeed could provide this new physics. The key elements of the model to be discussed are Trojan horse mechanism and coherent photon exchange action of D nuclei with Cooper pairs of the exotic super conductor formed by the D-loaded cathode material (say Palladium).

In the sequel the consideration is restricted to the case of Pd cathode: the model generalizes trivially to the case of a more general cathode material.

### 7.3.2 Signatures of cold fusion

In the following the consideration is restricted to cold fusion in which two deuterium nuclei react strongly since this is the basic reaction type studied.

In hot fusion there are three reaction types:

- 1)  $D + D \rightarrow {}^4\text{He} + \gamma$  (23.8MeV)
- 2)  $D + D \rightarrow {}^3\text{He} + n$
- 3)  $D + D \rightarrow {}^3\text{H} + p$ .

The rate for the process 1) predicted by standard nuclear physics is more than  $10^{-3}$  times lower than for the processes 2) and 3) [56]. The reason is that the emission of the gamma ray involves the relatively weak electromagnetic interaction whereas the latter two processes are strong.

The most obvious objection against cold fusion is that the Coulomb wall between the nuclei makes the mentioned processes extremely improbable at room temperature. Of course, this alone implies that one should not apply the rules of hot fusion to cold fusion. Cold fusion indeed differs from hot fusion in several other aspects.

1. No gamma rays are seen.
2. The flux of energetic neutrons is much lower than expected on basis of the heat production rate an by interpolating hot fusion physics to the recent case.

These signatures can also be (and have been!) used to claim that no real fusion process occurs. It has however become clear that the isotopes of Helium and also some tritium accumulate to the Pd target during the reaction and already now prototype reactors for which the output energy exceeds input energy have been built and commercial applications are under development, see for instance [59]. Therefore the situation has turned around. The rules of standard physics do not apply so that some new nuclear physics must be involved and it has become an exciting intellectual challenge to understand what is happening. A representative example of this attitude and an enjoyable analysis of the counter arguments against fold fusion is provided by the article 'Energy transfer in cold fusion and sono-luminescence' of Julian Schwinger [49]. This article should be contrasted with the ultra-skeptical article 'ESP and Cold Fusion: parallels in pseudoscience' of V. J. Stenger [50].

Cold fusion has also other features, which serve as valuable constraints for the model building.

1. Cold fusion is not a bulk phenomenon. It seems that fusion occurs most effectively in nano-particles of Pd and the development of the required nano-technology has made possible to produce fusion energy in controlled manner. Concerning applications this is a good news since there is no fear that the process could run out of control.



2. The ratio  $x$  of D atoms to Pd atoms in Pd particle must lie the critical range [.85, .90] for the production of  ${}^4\text{He}$  to occur [51]. This explains the poor repeatability of the earlier experiments and also the fact that fusion occurred sporadically.
3. Also the transmutations of Pd nuclei are observed [60].

Below a list of questions that any theory of cold fusion should be able to answer.

1. Why cold fusion is not a bulk phenomenon?
2. Why cold fusion of the light nuclei seems to occur only above the critical value  $x \simeq .85$  of D concentration?
3. How fusing nuclei are able to effectively circumvent the Coulomb wall?
4. How the energy is transferred from nuclear degrees of freedom to much longer condensed matter degrees of freedom?
5. Why gamma rays are not produced, why the flux of high energy neutrons is so low and why the production of  ${}^4\text{He}$  dominates (also some tritium is produced)?
6. How nuclear transmutations are possible?

## 7.4 TGD inspired model of cold fusion

The model to be discussed is based on Trojan horse mechanism and explains elegantly all those aspects of cold fusion which are in conflict with standard nuclear physics. The reaction mechanism explains also the sensitivity of the occurrence of cold fusion to small external perturbations.

### 7.4.1 Model for D-loaded Pd nano-particle

It seems that cold fusion is a critical phenomenon. The average  $D/Pd$  ratio must be in the interval (.85, .90). The current must be over-critical and must flow a time longer than a critical time. The effect occurs in a small fraction of samples. Deuterium at the surface of the cathode is found to be important and activity tends to concentrate in patches. The generation of fractures leads to the loss of the anomalous energy production. Even the shaking of the sample can have the same effect. The addition of even a small amount of  $H_2O$  to the electrolyte (protons to the cathode) stops the anomalous energy production.

All these findings support the catastrophe theoretic picture according to which the decomposition into patches corresponds to criticality allowing the presence of ordinary and exotic phase whose transformation to the ordinary phases makes possible cold fusion reactions. The added ordinary protons and fractures could serve as a seed for a phase transition leading to a region where only single phase is possible.

In TGD framework Pd nano-particles correspond to space-time sheets of size of order  $10^{-9} - 10^{-8}$  m and fusion is restricted inside these structures. Cold fusion can be regarded as a fusion of incoming ordinary D with target D attached to the surface of Pd rather than between two free D:s as suggested by the standard nuclear physics wisdom. Thus cold fusion could be regarded as 'burning' of  $D$  associated with a finite space-time sheets so that cold fusion is not a bulk phenomenon and is very sensitive to the in-homogenities of the Pd particle. Note that this in principle makes the control of cold fusion easier.

The critical loading fraction varies in the range .85 – .90. This value is so large that enormous pressures would be generated unless the deuterium nuclei lose their translational degrees of freedom by forming some kind of bound states with Pd nuclei. The guess is that the bound states correspond

to the formation of super-nuclei with em and weakly charged color bonds connecting Pd and D nuclei.  $k = 113$  dark weak force, which is actually strong by the criticality condition, compensates the color force between the exotic quarks. This makes D nuclei effectively nn nuclei so that Coulomb wall does not produce difficulties.

The challenge is to understand the origin of the criticality condition for super-nucleus. The question is why the number of D nuclei per Pd nuclei varies in so narrow range for the phase transition leading to the formation of super-nuclei to occur. Catastrophe theoretic thinking suggests that a cusp catastrophe typical for phase transitions is in question. In the critical range there are two phases, exotic and ordinary phase, which can easily transform to each other. Criticality is essential for the cold fusion reactions to occur since initial state involves exotic D+Pd complex and final state involves ordinary nuclei.

The ratio  $x$  would correspond to the variable which varies in a direction transversal to cusp and whose variation therefore leads to a catastrophic jump inducing the phase transition or its reverse.  $x$  would be a pressure type variable which plays similar role also in phase transitions like liquid-gas phase transition. The critical range for  $x$  would correspond to the critical range of pressure in which liquid and gas are in equilibrium.

Second variable varies along the cusp so that the transition is possible above certain critical value. This variable presumably relates to the energetics of the transition so that transition would liberate energy above critical value of the parameter. Temperature is a natural candidate for this variable. Catastrophe theoretic model implies that for a given value  $x$  in catastrophe region both ordinary phase and exotic phase are possible. In these regions cold fusion can occur. In regions where the system is outside the catastrophe region so that system is stably in either phase, cold fusion cannot occur. This explains why Pd contains only patches where cold fusion occurs. The control variable, be it local temperature or something else, could be perhaps identified by studying the local conditions guaranteeing the occurrence of cold fusion. It is indeed known that the increase of temperature favors the occurrence of cold fusion.

The behavior variable could distinguish between the two phases and could correspond to the surface density  $n$  of D nuclei bound to Pd nuclei and transformed to fake D. The potential function could be free energy minimized when the system is in constant temperature and the two phases would correspond to local minima of free energy.

#### 7.4.2 Anomalous reaction kinetics of cold fusion

One can deduce a more detailed model for cold fusion from observations, which are discussed systematically in [56] and in the references discussed therein.

1. When  $D_2O$  is used as an electrolyte, the process occurs when  $PdD$  acts as a cathode but does not seem to occur when it is used as anode. This suggests that the basic reaction is between the ordinary deuterium  $D = pn$  of electrolyte with the the exotic D=nn + charged color bond attached to Pd in the cathode.
2. For ordinary nuclei fusions to tritium and  $^3He$  occur with approximately identical rates. The first reaction produces neutron and  $^3He$  via  $D + D \rightarrow n + ^3He$ , whereas second reaction produces proton and tritium via  $D + D \rightarrow p + ^3H$ . The standard nuclear physics prediction is that one neutron per each tritium nucleus should be produced. Tritium can be observed by its beta decay to  $^3He$  and the ratio of neutron flux is several orders of magnitude smaller than tritium flux as found for instance by Tadahiko Mizuno and his collaborators (Mizuno describes the experimental process leading to this discovery in his book [54]). Hence the reaction producing  $^3He$  cannot occur significantly in cold fusion which means a conflict with the basic predictions of the standard nuclear physics.

The explanation is following. If D is fake D (nn+charged color bond connecting it with Pd), one expects that the production of  ${}^3\text{He}$  is hindered since there is no proton directly available. Also in the case that the reaction  $n+\text{color bond} \rightarrow p$  occurs, one expects that Coulomb wall makes the process slow.

3. The production of  ${}^4\text{He}$ , which should not occur practically at all, is reported to dominate and the fraction of tritium is below .1 per cent. The explanation could be that also multiple attachments to target can occur such that D attaches to (D+Pd) by forming a charged color bond. Thus would have nnnnn state with two charged color bonds attached to Pd. This state could split from Pd and transform via exchange of two light weak bosons between exotic and valence quarks to  ${}^4\text{He}$  (assuming that dark  $W(113)$  can mix with  $W(89)$ ). It is also possible that the super-nuclear string formed by Pd and D splits and emits  ${}^4\text{He}$  as in ordinary alpha decay. Gamma rays need not be generated since the recoil momentum could be transferred to the Pd target like in Mössbauer effect.
4. Also more complex reactions between  $D$  and  $Pd$  and between Pd nuclei can occur. These can lead to the reactions transforming the nuclear charge of  $Pd$  and thus to nuclear transmutations.
5. The mechanism also explains why the cold fusion producing  ${}^3\text{He}$  and neutrons does not occur using water instead of heavy water. There are reports about cold fusion also in this case [55]. If one fourth of protons in water are arranged to nuclear strings consisting of neutrons connected by positively charged color bonds as the TGD based model explaining the anomalies of water suggests [F10], these strings could attach to fake D and induce cold fusion reactions.
6. The proposed reaction mechanism explains why neutrons are not produced in amounts consistent with the anomalous energy production. The addition of water to the electrolyte however induces neutron bursts. Suppose that one fourth of protons in water forms similar dark phase being transformed to neutrons connected by positively charged color bonds, as assumed in the model of water explaining various anomalies of water [F10]. What comes in mind is that neutrons are generated when a neutron string from  $\text{H}_2\text{O}$  containing only charged color bonds attaches to D+Pd (nn + charged color bond +Pd). Neutrons of nn are connected by a neutral color bond. If charged color bonds between neutrons are energetically more favorable than neutral color bonds,  $nn$  could emit a free neutron in the process so that the outcome would be a neutron string containing only charged color bonds attached to Pd.

### 7.4.3 How objections against cold fusion are circumvented?

It has already become clear that the model allows to circumvent the basic reaction kinetic arguments against cold fusion [56].

1. Coulomb wall makes nuclear fusions impossible.
2.  ${}^3\text{He}$  and  ${}^3\text{H}$  should be produced in equal amounts. The fraction of  ${}^4\text{He}$  should be smaller than  $10^{-3}$ .
3. The claimed nuclear transmutation reactions (reported to occur also in living matter [63]) should not occur.

Consider next the objections related to energetics.

1. Gamma rays, which should be produced in most nuclear reactions such as  ${}^4\text{He}$  production to guarantee momentum conservation are not observed. The explanation is that the recoil momentum goes to the macroscopic quantum phase defined by the Pd lattice as in Mössbauer effect, and eventually heats the electrolyte system. This provides the mechanism by which the liberated nuclear energy is transferred to the electrolyte difficult to imagine in standard nuclear physics framework.
2. If a nuclear reaction should occur, the immediate release of energy can not be communicated to the lattice in the time available. In the recent case the time scale is however multiplied by the factor  $r = \hbar_s/\hbar$  giving scaling factor  $2^{11}$  so that the situation changes dramatically.

## 7.5 Do nuclear reaction rates depend on environment?

Claus Rolfs and his group have found experimental evidence for the dependence of the rates of nuclear reactions on the condensed matter environment [67]. For instance, the rates for the reactions  ${}^{50}\text{V}(p,n){}^{50}\text{Cr}$  and  ${}^{176}\text{Lu}(p,n)$  are fastest in conductors. The model explaining the findings has been tested for elements covering a large portion of the periodic table.

### 7.5.1 Debye screening of nuclear charge by electrons as an explanation for the findings

The proposed theoretical explanation [67] is that conduction electrons screen the nuclear charge or equivalently that incoming proton gets additional acceleration in the attractive Coulomb field of electrons so that the effective collision energy increases so that reaction rates below Coulomb wall increase since the thickness of the Coulomb barrier is reduced.

The resulting Debye radius

$$R_D = 69 \sqrt{\frac{T}{n_{eff}\rho_a}} , \quad (22)$$

where  $\rho_a$  is the density of atoms per cubic meter and  $T$  is measured in Kelvins.  $R_D$  is of order .01 Angstroms for  $T = 373$  K for  $n_{eff} = 1$ ,  $a = 10^{-10}$  m. The theoretical model [65, 66] predicts that the cross section below Coulomb barrier for  $X(p, n)$  collisions is enhanced by the factor

$$f(E) = \frac{E}{E + U_e} \exp\left(\frac{\pi\eta U_e}{E}\right) . \quad (23)$$

$E$  is center of mass energy and  $\eta$  so called Sommerfeld parameter and

$$U_e \equiv U_D = 2.09 \times 10^{-11} (Z(Z+1))^{1/2} \times \left(\frac{n_{eff}\rho_a}{T}\right)^{1/2} \text{ eV} \quad (24)$$

is the screening energy defined as the Coulomb interaction energy of electron cloud responsible for Debye screening and projectile nucleus. The idea is that at  $R_D$  nuclear charge is nearly completely screened so that the energy of projectile is  $E + U_e$  at this radius which means effectively higher collision energy.

The experimental findings from the study of 52 metals support the expression for the screening factor across the periodic table.

1. The linear dependence of  $U_e$  on  $Z$  and  $T^{-1/2}$  dependence on temperature conforms with the prediction. Also the predicted dependence on energy has been tested [67].

2. The value of the effective number  $n_{eff}$  of screening electrons deduced from the experimental data is consistent with  $n_{eff}(Hall)$  deduced from quantum Hall effect.

The model suggests that also the decay rates of nuclei, say beta and alpha decay rates, could be affected by electron screening. There is already preliminary evidence for the reduction of beta decay rate of  $^{22}\text{Na}$   $\beta$  decay rate in Pd [68], metal which is utilized also in cold fusion experiments. This might have quite far reaching technological implications. For instance, the artificial reduction of half-lives of the radioactive nuclei could allow an effective treatment of radio-active wastes. An interesting question is whether screening effect could explain cold fusion [56] and sono-fusion [69].

### 7.5.2 Electron screening and Trojan horse mechanism

These experimental findings allow to quantify the Trojan horse mechanism. The idea is that projectile nucleus enters the region of the target nucleus along a larger space-time sheet and in this manner avoids the Coulomb wall. The nuclear reaction itself occurs conventionally. In conductors the space-time sheet of conduction electrons is a natural candidate for the larger space-time sheet.

At conduction electron space-time sheet there is a constant charged density consisting of  $n_{eff}$  electrons in the atomic volume  $V = 1/n_a$ . This creates harmonic oscillator potential in which incoming proton accelerates towards origin. The interaction energy at radius  $r$  is given by

$$V(r) = \alpha n_{eff} \frac{r^2}{2a^3} , \quad (25)$$

where  $a$  is atomic radius.

The proton ends up to this space-time sheet by a thermal kick compensating the harmonic oscillator energy. This occurs below with a high probability below radius  $R$  for which the thermal energy  $E = T/2$  of electron corresponds to the energy in the harmonic oscillator potential. This gives the condition

$$R = \sqrt{\frac{Ta}{n_{eff}\alpha}} a . \quad (26)$$

This condition is exactly of the same form as the condition given by Debye model for electron screening but has a completely different physical interpretation.

Since the proton need not travel through the nuclear Coulomb potential, it effectively gains the energy

$$E_e = Z \frac{\alpha}{R} = \frac{Z\alpha^{3/2}}{a} \sqrt{\frac{n_{eff}}{Ta}} . \quad (27)$$

which would be otherwise lost in the repulsive nuclear Coulomb potential. Note that the contribution of the thermal energy to  $E_e$  is neglected. The dependence on the parameters involved is exactly the same as in the case of Debye model. For  $T = 373$  K in the  $^{176}\text{Lu}$  experiment and  $n_{eff}(Lu) = 2.2 \pm 1.2$ , and  $a = a_0 = .52 \times 10^{-10}$  m (Bohr radius of hydrogen as estimate for atomic radius), one has  $E_e = 28.0$  keV to be compared with  $U_e = 21 \pm 6$  keV of [67] ( $a = 10^{-10}$  m corresponds to  $1.24 \times 10^4$  eV and 1 K to  $10^{-4}$  eV). A slightly larger atomic radius allows to achieve consistency. The value of  $\hbar$  does not play any role in this model since the considerations are purely classical.

An interesting question is what the model says about the decay rates of nuclei in conductors. For instance, if the proton from the decaying nucleus can enter directly to the space-time sheet

of the conduction electrons, the Coulomb wall corresponds to the Coulomb interaction energy of proton with conduction electrons at atomic radius and is equal to  $\alpha n_{eff}/a$  so that the decay rate should be enhanced.

Trojan horse mechanism realized in this manner does not seem to explain the basic findings about cold fusion. Trojan horse mechanism applied to deuterium projectile and D-Pd target would predict standard nuclear physics. The reported strong suppression of  ${}^3\text{He}$  production with respect to  ${}^3\text{H}$  production however requires non-standard nuclear physics and the model discussed in the previous subsection provides this physics. Both mechanisms could of course be involved.

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